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AIT
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DREO REPORT

FINAL REPORT

MULTI FUNCTION RADAR ELECTRONIC COUNTER COUNTER MEASURE STUDIES

SSC FILE NUMBER 027ST.W7714-2-9607
OCTOBER 1992 TO NOVEMBER 1993

Prepared by:
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November 1993

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Date	November/93					

Table of Contents

1.0 Introduction 1
  1.1 Project Background 1
  1.2 AIT Project Organization 3
  1.3 Statement of Work 3
    1.3.1 Main-Beam and Sidelobe Canceller Simulator Development 3
    1.3.2 Monopulse Sensitivity to Array Tilt Analysis 4
    1.3.3 Radar Trial Support 4

2.0 Contract Management 5
  2.1 Project Team Organization 5
  2.2 Project Control 5

3.0 Main Beam and Sidelobe Canceller Simulator Development 7
  3.1 Task 1a) Simulator Development 7
  3.2 Task 1b) Coding and Testing of Sidelobe Cancellation Software 27
  3.3 Task 1c) Data Analysis and Testing the Effectiveness of the Sidelobe Canceller Software 34

4.0 Monopulse Sensitivity to Array Tilt Analysis 50

5.0 Radar Trials Support 52

APPENDIX A Statement of Work A1

APPENDIX B EARS Project Personnel B1

APPENDIX C Task Sheets C1

APPENDIX D Source Listings of Programs and Subroutines D1

APPENDIX E Table of Statistics for Figure 5.2 .... E1

APPENDIX F Brief Description of Sidelobe Cancellation Algorithm F1

APPENDIX G Monthly Reports G1

APPENDIX H List of Figures H1

APPENDIX I References I1

1.0 Introduction

This report summarizes the work performed on the AIT contract running from October 1992 to November 1993. The contract followed the statement of work outlined in Contract W7714-2-9607 (Appendix A) entitled "Multi Function Radar Electronic Counter Counter Measure Studies". This document will refer to work done primarily by AIT personnel. The work on this contract was carried out by Mr. Dan Brookes and Ms. Anna Wilkinson. Some work was performed in conjunction with other project personnel. Appendix B displays a list of the Experimental Array Radar System (EARS) Project personnel.

1.1 Project Background

The tracking of a target for a naval fire-control radar requires a continuous determination of the target range, height and azimuth. In low-angle situations the target height is difficult to determine due to propagation effects on the signal, multipath being the major source of problems. Figure 1.1 illustrates the multipath effect, where two rays (the direct and indirect) are reflected from the target back to the receiver via different paths. The combination of the target (direct) and image (indirect) signals, which are essentially coherent, results in a complex returned signal that often confuses conventional tracking radars. In addition to this basic physical problem, an enemy may try to further confuse the tracking radar by making use of frequency jamming techniques. The purpose of this contract was to assist the Surface Radar Section at the Defence Research Establishment Ottawa (DREO) with carrying out certain aspects of research on multi-function radar (MFR); the major emphasis being placed on Electronic Counter Counter Measures (ECCM) of MFR, including sidelobe and main-beam nulling of jamming signals. The studies were carried out using a combination of both simulated and real experimental data. The majority of the experimental data was acquired with the Experimental Array Radar System (EARS) located at the Area 5 test site located along the Ottawa river.

The EARS consisted of an inverted 'T' array configuration with a vertical eight element array, for the main beam, centred just above a horizontal eight element array. The horizontal array was intended for use as the sidelobe canceller (SLC) array. In later upgrades to the system a Rotman lens was attached to the horizontal array to perform instantaneous RF beamforming.

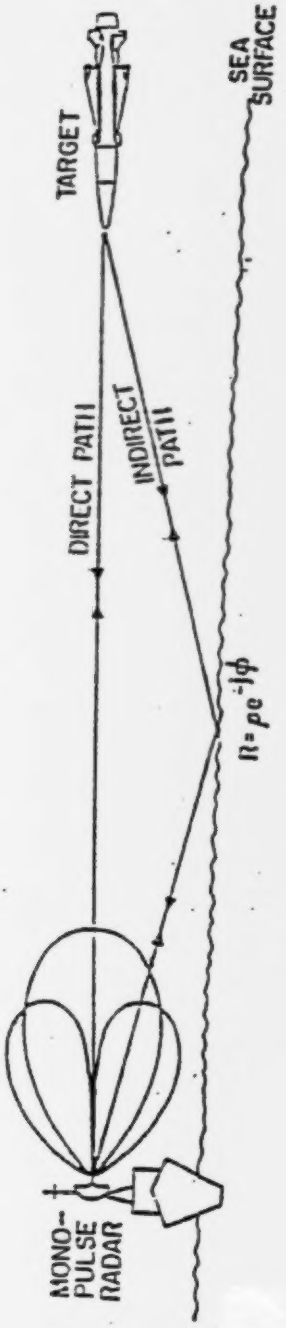

TARGET
SEA SURFACE
DIRECT PATH
INDIRECT PATH
$R = \rho e^{-j\phi}$
MONO-PULSE RADAR

Figure 1.1: The Low Angle Tracking Problem

1.2 AIT Project Organization

The management structure proposed for this contract was originally outlined in the proposal for "Multi Function Radar Electronic Counter Counter Measure Studies- Part I- Technical and Management Proposal". This will be restated in Section 2 of this report.

1.3 Statement of Work

The statement of work was originally divided into 3 main tasks:

1) Main-Beam and Sidelobe Canceller Simulator Development
2) Monopulse Sensitivity to Array Tilt Analysis
3) Radar Trial Support

Each main heading often consisted of several additional sub tasks as will be shown in the report to follow.

1.3.1 Main-Beam and Sidelobe Canceller Simulator Development

This task was divided into 3 sub tasks, a) to c). Task 1a) was to develop simulators for generating data inputs for main-beam and sidelobe cancellation programs, given the relative geometry of the target, receiver and jammer(s). The simulators were to include antenna gain patterns for the main-beam and sidelobe canceller receivers and to include possible dispersive properties of the main and sidelobe receivers. There was also a requirement that the simulators should model sampling of the target and surrounding range cells to correspond to a real time environment.

The purpose of Task 1b) was to convert algorithms supplied by the Scientific Authority into computer simulators for main-beam and sidelobe cancellation, then perform sensitivity experiments on the algorithms.

Task 1c) involved the conversion of experimental data into the form used by the main-beam and sidelobe cancellation simulators and to analyse the effectiveness of the simulators. In the original statement of work the "experimental data" referred to the results of experiments conducted in June of 1990 during sea trials with an experimental radar system using Sea King helicopters. However, over the course of this contract additional experiments were carried out with the EARS at Area 5 which were considered more useful and thus superseded the previous results in terms of importance.

1.3.2 Monopulse Sensitivity to Array Tilt Analysis

The original purpose of this task was to perform an analysis on the effect of array tilt due to ship's motion on monopulse performance in the presence of multipath. It was originally intended that a simple antenna array was to be used to conduct these analyses; however, over the course of the contract the importance of this task evolved along with the complexity of the simulator being created. In the end a quite complex 2-dimensional phased array simulator was created to carry out these analyses.

1.3.3 Radar Trial Support

The contractor provided support during several sets of experimental trials carried out at Area 5 during the course of the contract. This included the development of computer programs to read and pre-screen some of the experimental data on site. This helped in determining the data quality and possible usefulness.

2.0 Contract Management

Mr. Ed Riseborough of the DREO-Surface Radar Section was the Scientific Authority for duration of the contract. He was responsible for handling contracting matters (for DREO), specifying objectives, setting time-frames, stating the technical approach desired, and resetting priorities according to the changing circumstances of the research. A continual interaction was maintained between the Scientific Authority and contract personnel to determine progress and obtain results which would orient the direction of the research. A project Manager was supplied by AIT to ensure that the contracted commitments were met and a Project Leader was also supplied to provide the necessary technical leadership and supervision on site.

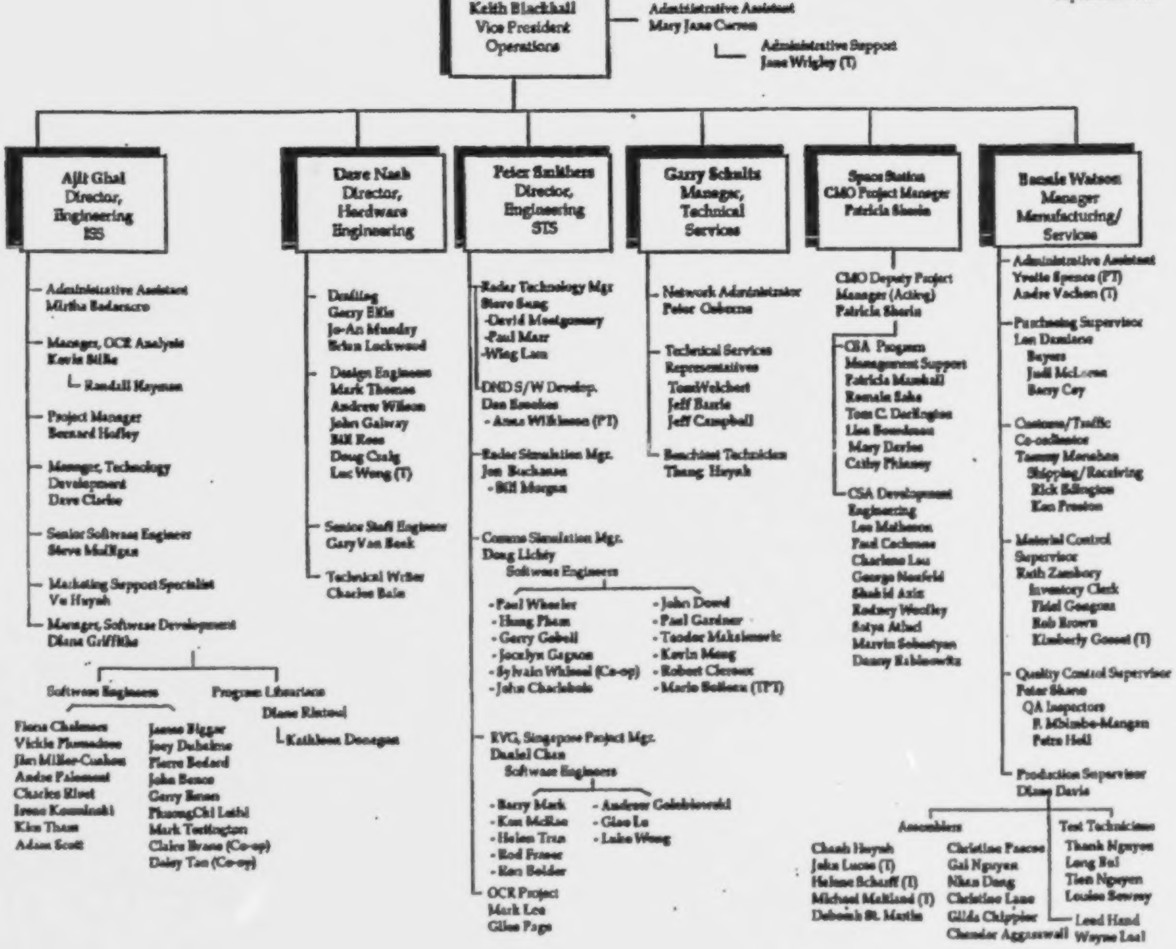
2.1 Project Team Organization:

The nature of the AIT Project Team is identified below and the AIT Systems Organization Chart is shown in Figure 2.1.

Position Title	Responsibilities
Project Manager	Contract Management
Project Leader/ Scientific Analyst	Tasking and Scheduling Review of Documentation Technical coordination Data Analysis Scientific Reporting Trials Support
Senior Programmer	Assist Scientific Analyst

2.2 Project Control

A set of task sheets was prepared for the Scientific Analyst and the Senior Programmer. These were accepted by the Scientific Authority (see Appendix C). Monthly reports of activities were also produced (see Appendix G).


Keith Blackhall
Vice President
Operations
Administrative Assistant
Mary Jane Carron
Administrative Support
Jane Wrigley (T)
Ajit Ghai
Director,
Engineering
ISS
Administrative Assistant
Mirtha Bedarnero
Manager, OCR Analysis
Kevin Bilke
Randall Heyman
Project Manager
Bernard Hofley
Manager, Technology
Development
Dave Clarke
Senior Software Engineer
Steve Mulligan
Marketing Support Specialist
Vu Huynh
Manager, Software Development
Diana Griffiths
Software Engineers
Fiona Chalmers
Vickie Plamadore
Jim Miller-Cushon
Andre Paiement
Charles Rivet
Irene Kaminski
Kim Tham
Adam Scott
James Biggar
Joey Dubaime
Pierre Bedard
John Bence
Garry Bmen
PhuongChi Lathi
Mark Tottington
Claire Brame (Co-op)
Daisy Tan (Co-op)
Program Librarians
Diane Rintoul
Kathleen Donegan
Dave Nash
Director,
Hardware
Engineering
Drafting
Garry Ellis
Jo-An Munday
Brian Lockwood
Design Engineers
Mark Thomas
Andrew Wilson
John Galway
Bill Ross
Doug Craig
Luc Wong (T)
Senior Staff Engineer
Gary Van Beek
Technical Writer
Charles Bain
Peter Smithers
Director,
Engineering
STS
Radar Technology Mgr
Steve Sang
-David Montgomery
-Paul Marr
-Wing Lam
DND S/W Develop.
Dan Emerson
- Anna Wilkinson (PT)
Radar Simulation Mgr.
Jon Buchanan
- Bill Morgan
Comms Simulation Mgr.
Doug Lichty
Software Engineers
- Paul Wheeler
- Hung Pham
- Gerry Gebell
- Jocelyn Gagnon
- Sylvain Whiteal (Co-op)
- John Chaclebois
- John Dowd
- Paul Gardner
- Teodor Maksimovic
- Kevin Meng
- Robert Clereaux
- Mario Bolleux (TPT)
KVG, Singapore Project Mgr.
Daniel Chan
Software Engineers
- Barry Mark
- Ken McRae
- Helen Tran
- Rod Fraser
- Ken Belder
- Andrew Golebiowski
- Giao Le
- Luke Wong
OCR Project
Mark Lee
Giles Page
Garry Schultz
Manager,
Technical
Services
Network Administrator
Peter Osborne
Technical Services
Representatives
Tom Welchert
Jeff Basle
Jeff Campbell
Benchtest Technician
Thang Huynh
Space Station
CMO Project Manager
Patricia Sherin
CMO Deputy Project
Manager (Acting)
Patricia Sherin
CSA Program
Management Support
Patricia Marshall
Romain Saha
Tom C. Darlington
Lisa Boardman
Mary Davies
Cathy Phinney
CSA Development
Engineering
Lee Matheson
Paul Cochrane
Charlene Lau
George Neufeld
Shahid Aziz
Rodney Woolley
Satya Atled
Marvin Sebastyan
Danny Rabinowitz
Rosanie Watson
Manager
Manufacturing/
Services
Administrative Assistant
Yvette Spence (PT)
Andre Vachon (T)
Purchasing Supervisor
Len Damiano
Buyers
Judi McLean
Barry Coy
Customs/Traffic
Co-ordinator
Tammy Monahan
Shipping/Receiving
Rick Billington
Ken Preston
Material Control
Supervisor
Ruth Zambory
Inventory Clerk
Fidel Gongora
Rob Brown
Kimberly Gosset (T)
Quality Control Supervisor
Peter Shane
QA Inspectors
P. Mbimbe-Mangan
Petra Hell
Production Supervisor
Diane Davis
Assemblers
Chanh Huynh
John Lucas (T)
Helene Schaff (T)
Michael Maitland (T)
Deborah St. Martin
Christine Pascoe
Gai Nguyen
Nhan Dang
Christine Lane
Gilda Chippier
Chander Aggarwall
Test Technicians
Thanh Nguyen
Long Bui
Tien Nguyen
Louise Sowrey
Lead Hand
Wayne Leal

Valerie Delorme
September 1993

Figure 2.1 A I T Corp. organization chart

3.0 Main Beam and Sidelobe Canceller Simulator Development

3.1 Task 1a) Simulator Development

In order to carry out realistic simulations for main-beam and sidelobe cancellers, it was decided that the simulators should resemble, as closely as possible, the actual system employed in the EARS at the Area 5. As outlined earlier, the EARS consisted of two perpendicular arrays; the vertical, or main-beam, eight element array was centred just above a horizontal eight element array. The horizontal array was intended for use as the sidelobe canceller (SLC) array. In later upgrades to the system a Rotman lens was attached to the horizontal array to do instantaneous beamforming.

The geometry of the EARS is shown in Figure 3.1. The main beam array consisted of eight horn-pair elements equally spaced over an aperture of 0.875 metres. Each half of a horn-pair was a pyramidal horn 6.25 cm in height by 4.0 cm in width and approximately 12.5 cm in length. The outputs of each half of a horn-pair were combined to give a single output. The horizontal array consisted of eight Narda 640 standard gain, pyramidal horns equally spaced over an aperture of 1.0 metre. Each Narda horn had dimensions of approximately 7.86 cm in height by 5.95 cm in width and a length of about 12.86 cm. Both the horizontal and vertical array were set up to receive microwave radiation with the E field horizontally polarized. The 1.4 meter high parabolic reflector shown in Figure 3.1 was used to compress the azimuthal beam pattern of the vertical array to about 4.5 degrees. According to the manufacturers (i.e. STC) specifications, the reflector was arranged to allow a 20 cm overlap at each end of the vertical array. It had an F/D ratio of 0.3, a focal length of 36 cm and an offset aperture of 60 cm. The feed column pointing angle was set to 45 degrees. Due to anticipated difficulty modelling the reflector portion of the array it was decided that for the purposes of these initial simulations just using the two arrays would suffice. The new configuration is shown in Figure 3.2.

Two different theoretical models were tested to obtain a reasonable match to the actual measured elevation amplitude and phase patterns of the horn-pairs for the vertical array. Since each half of a horn-pair was, in reality, a pyramidal horn with the dimensions given above, it was assumed that the model should reflect this.

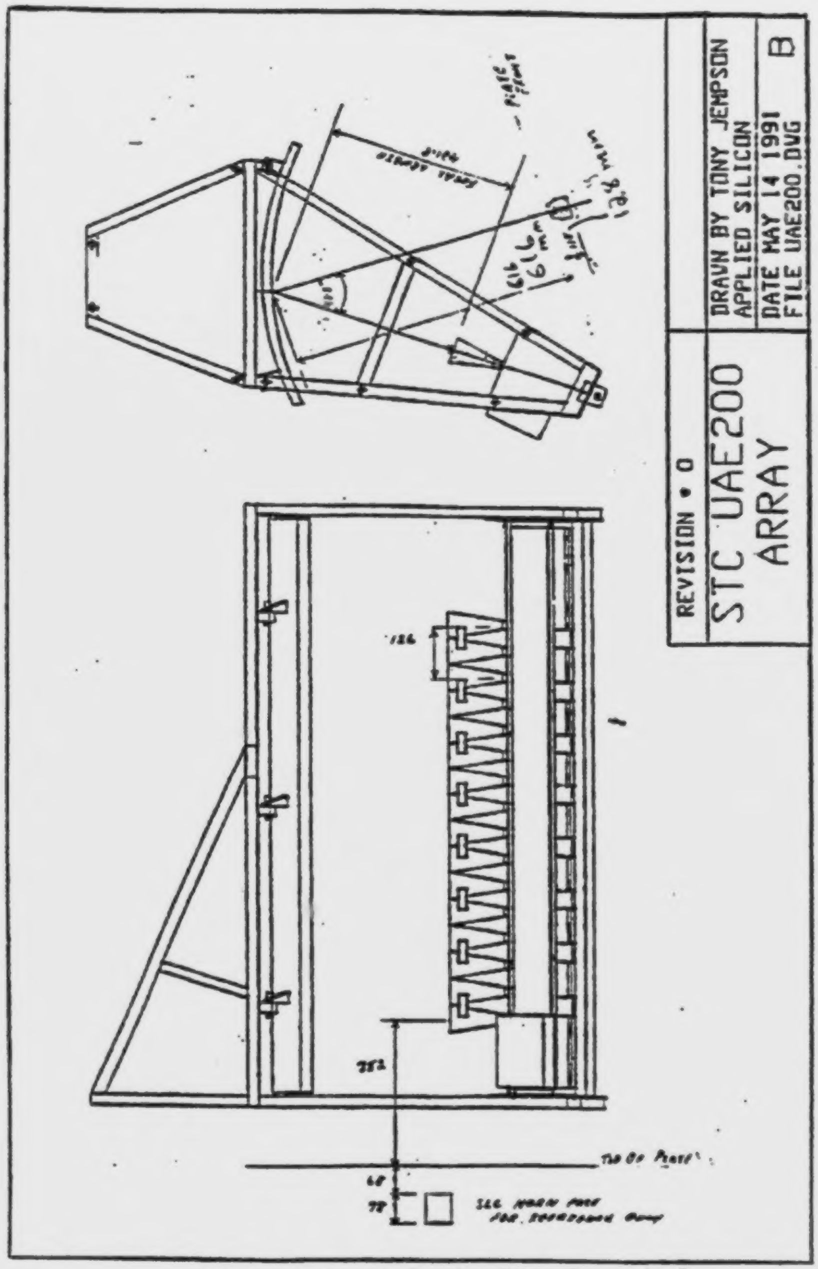

REVISION • 0
STC UAE200 ARRAY
DRAWN BY TONY JEMPSON
APPLIED SILICON
DATE MAY 14 1991
FILE UAE200.DWG
B
616 mm
12.8 mm
126
252
68
78
TOP OF PLATE
SEE MAIN PART FOR SECONDARY ARRAY

Figure 3.1 - Scale drawing of vertical main-beam array

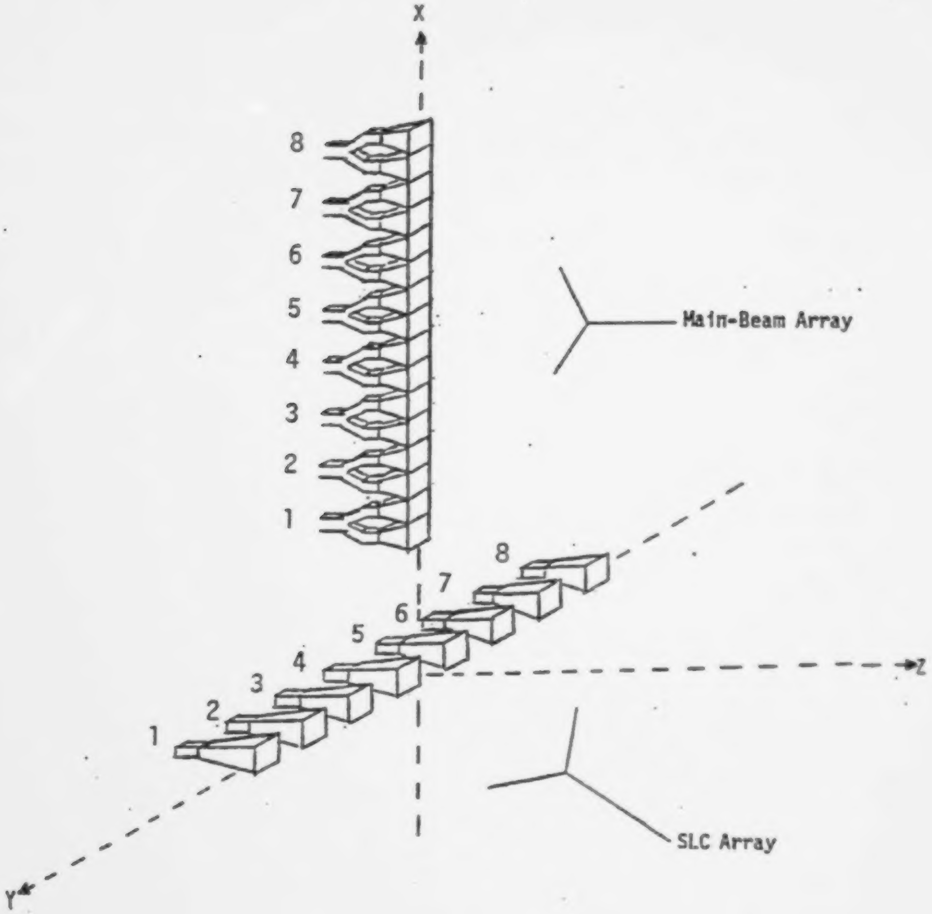

X
8
7
6
5
4
3
2
1
Main-Beam Array
8
7
6
5
4
3
2
1
Z
Y
SLC Array

Figure 3.2 - Schematic diagram of receiver system used in simulations

According to Balanis [1], the radiation pattern for a pyramidal horn transmitting or receiving horizontally polarized radiation (assuming dominant TE_{10} mode) should be given by the following formulas:

$$E_r = 0$$

$$E_\Theta = j \cdot A \cdot (e^{-jkr}/r) \cdot \sin\phi \cdot \exp[jk_y^2 \cdot \rho_1/(2k)] \cdot I_1 \cdot I_2$$

$$E_\phi = j \cdot A \cdot (e^{-jkr}/r) \cdot \cos\phi \cdot \exp[jk_y^2 \cdot \rho_1/(2k)] \cdot I_1 \cdot I_2$$

where

$$I_1 = (1+\cos\Theta) \cdot [\exp(jk_x'^2 \cdot \rho_2/(2k)) \cdot F(t_1', t_2') + \exp(jk_x''^2 \cdot \rho_2/(2k)) \cdot F(t_1'', t_2'')]$$

$$I_2 = \exp(jk_y^2 \, \rho_1/(2k)) \cdot F(t_1, t_2)$$

$$F(t_1, t_2) = [C(t_2) - C(t_1)] - j \cdot [S(t_2) - S(t_1)]$$

$$C(t) = \int_0^t \cos(\pi \cdot x^2/2) \cdot dx = \text{Fresnel cosine integral}$$

$$S(t) = \int_0^t \sin(\pi \cdot x^2/2) \cdot dx = \text{Fresnel sine integral}$$

$$k_x' = k \cdot \sin\Theta \cdot \cos\phi + \pi/a_1$$

$$k_x'' = k \cdot \sin\Theta \cdot \cos\phi - \pi/a_1$$

$$k_y = k \cdot \sin\Theta \cdot \sin\phi$$

$$t_1 = (1/(k \, \pi\rho_1))^{1/2}(-k \cdot b_1/2 - k_y \cdot \rho_1)$$

$$t_2 = (1/(k \, \pi\rho_1))^{1/2}(k \cdot b_1/2 - k_y \cdot \rho_1)$$

$$t_1' = (1/(k \, \pi\rho_1))^{1/2}(-k \cdot b_1/2 - k_x' \cdot \rho_2)$$

$$t_2' = (1/(k \, \pi\rho_1))^{1/2}(k \cdot b_1/2 - k_x' \cdot \rho_2)$$

$$t_1'' = (1/(k \, \pi\rho_1))^{1/2}(-k \cdot b_1/2 - k_x'' \cdot \rho_2)$$

$$t_2'' = (1/(k \, \pi\rho_1))^{1/2}(k \cdot b_1/2 - k_x'' \cdot \rho_2)$$

$k = 2\pi/\lambda$; λ = wavelength and Θ and ϕ are the spherical polar coordinates shown in Figure 3.3 (c). The other parameters included in the above formulas are defined through illustration in Figure 3.3 (a) and (b). Although a diagram of the H-plane view is not included in Figure 3.3, it is easily inferred by (b). The geometry of a single horn-pair with respect to a microwave radiation source (eg. a beacon) is illustrated in Figure 3.4. The E field in the vertical direction of the x-z plane (also called the H-plane direction) can be obtained by setting $\phi = \pi/2$ and letting Θ be positive or negative (in the general definition of spherical coordinates Θ is always positive). By inserting the actual physical dimensions of a horn-pair into the above formulas, their combined output should produce amplitude and phase plots as shown in Figure 3.5 and 3.6 for 9.6 and 8.6 GHz respectively, assuming the measurements were made in the same manner as in the original STC tests published. These tests were described in a report supplied by STC to the Scientific Authority and also published in a report [2] by A. Pearson et. al. entitled "An Array-fed Reflector Antenna With Built-in Calibration Facility". It can be seen from the plots that the agreement between the theoretical and measured amplitude and phase patterns is not very satisfactory using this model. (Note: in Figures 3.5 to 3.8, the parameters a1 and d1 correspond to a_1 and ρ_1 of Figure 3.3 (b) whereas z refers to the horizontal distance from the front face of the receiver elements to the radiation source.)

The second model for the elevation patterns of the horn-pairs assumed that each half of the horn-pair was represented by an E-plane sectoral horn with the radiation pattern measured in the H-plane direction (i.e. the direction perpendicular to the horizontally polarized E vector). The electric field amplitude and phase for this model are given by the formulas:

$$E_r = 0$$

$$E_\Theta = -j \cdot A \cdot (e^{-jkr}/r) \cdot \sin\phi \cdot (\exp(jk_y^2 \cdot \rho_1/(2k)) \cdot I_1 \cdot F(t_1, t_2)$$

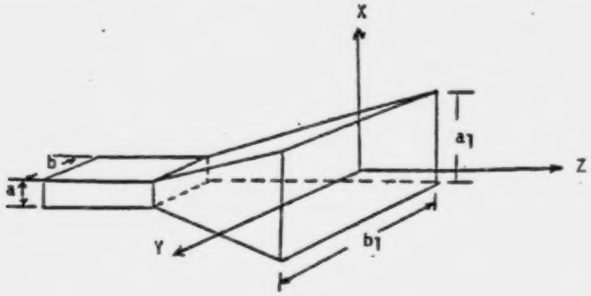
$$E_\phi = -j \cdot A \cdot (e^{-jkr}/r) \cdot \cos\phi \cdot (\exp(jk_y^2 \cdot \rho_1/(2k)) \cdot I_1 \cdot F(t_1, t_2)$$

where

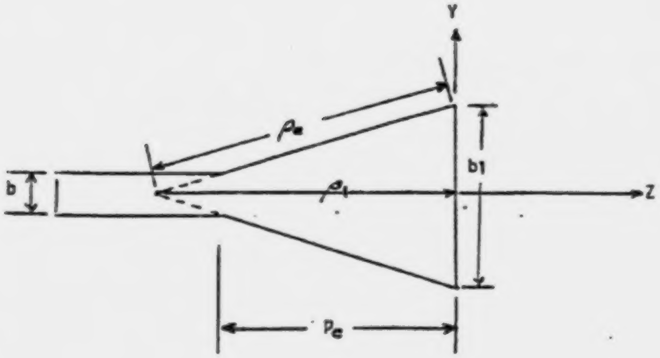
$$I_1 = (1 + \cos\Theta) \cdot \cos(k_x \cdot a_1/2)/((k_x \cdot a_1/2)^2 - (\pi/2)^2)$$

$$k_x = k \cdot \sin\Theta \cdot \cos\phi$$

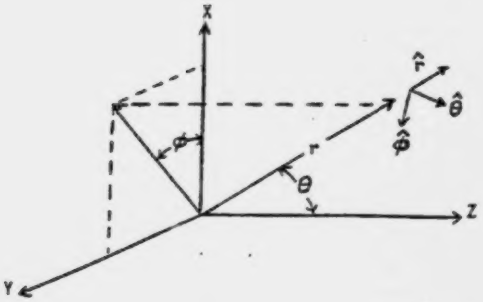
$$k_y = k \cdot \sin\Theta \cdot \sin\phi$$



(a) Pyramidal horn


Y
Z
b
b1
ρ_e
ρ_1
P_e

(b) E-plane view


X
Y
Z
r
$\hat{r}$
$\hat{\theta}$
$\hat{\phi}$
ϕ
θ

(c) Spherical Polar Coordinates

Figure 3.3 Pyramidal horn geometry and coordinate system

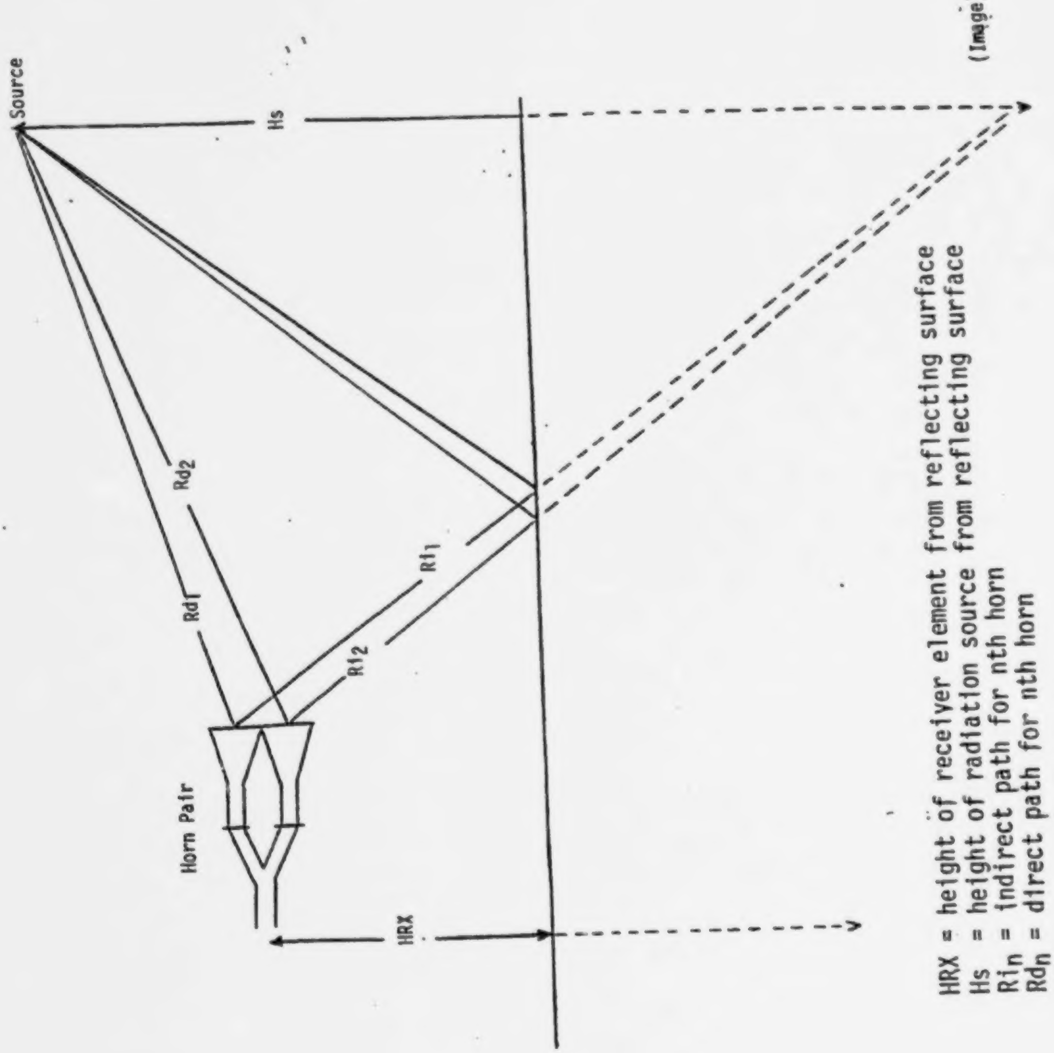

Source
Hs
(Image)
Rd2
Rd1
Ri1
Ri2
Horn Pair
HRX
HRX = height of receiver element from reflecting surface
Hs = height of radiation source from reflecting surface
Ri$_n$ = indirect path for nth horn
Rd$_n$ = direct path for nth horn

Figure 3.4 Horn pair geometry in multipath environment

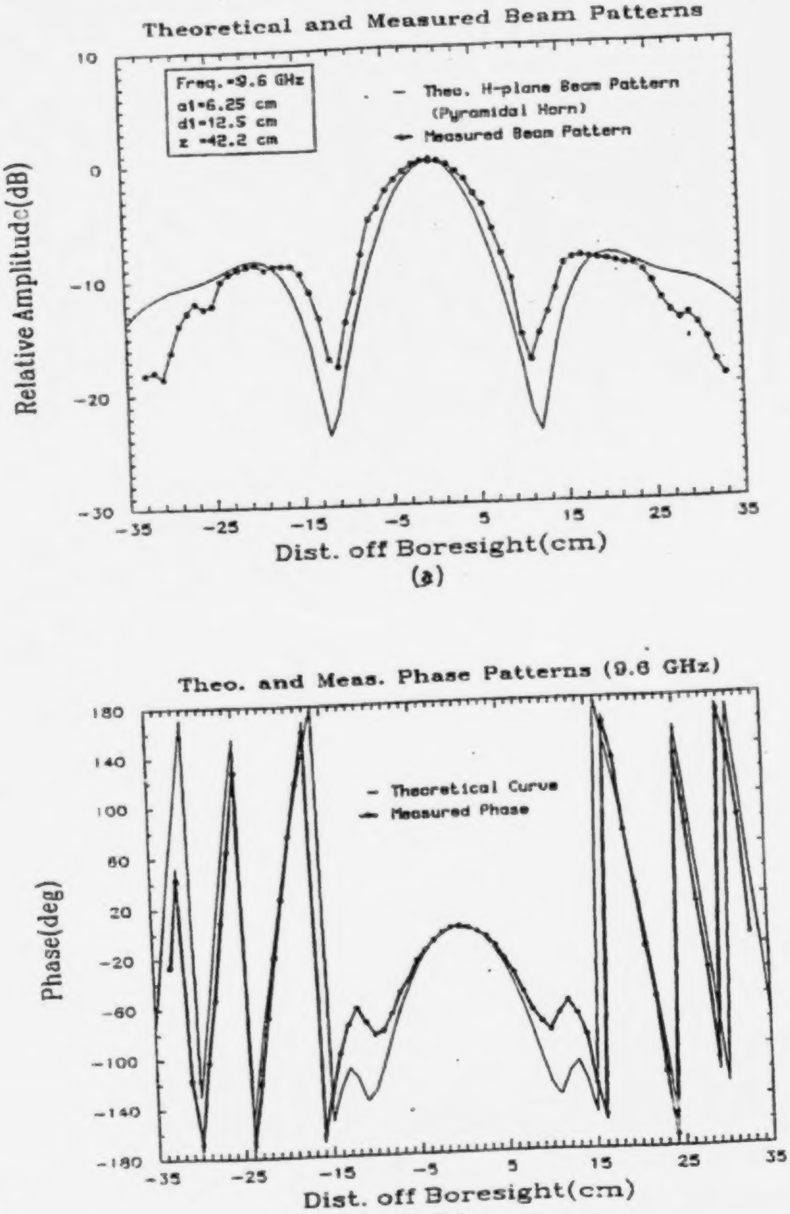
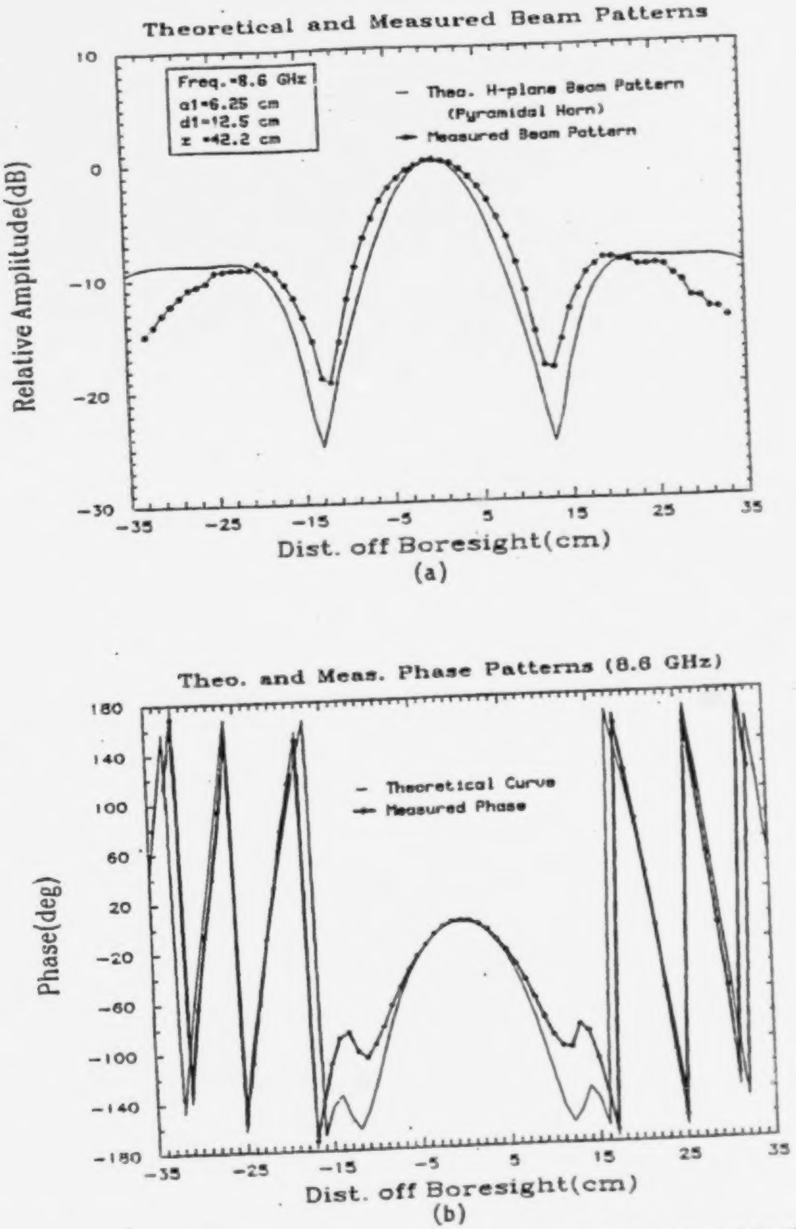


Figure 3.5 Comparison between theoretical and measured amplitude and phase patterns assuming pyramidal horn geometry at 9.6 GHz



(a)

(b)

Figure 3.6 Comparison between theoretical and measured amplitude and phase patterns assuming pyramidal horn geometry at 8.6 GHz

$$t_1 = (1/(k\ \pi\rho_1))^{1/2}(-k \cdot b_1/2 - k_y \cdot \rho_1)$$

$$t_2 = (1/(k\ \pi\rho_1))^{1/2}(k \cdot b_1/2 - k_y \cdot \rho_1)$$

A comparison between the actual measured and theoretical elevation amplitude and phase patterns for a horn-pair at 9.6 and 8.6 GHz is shown in Figures 3.7 and 3.8 respectively. It can be seen that the agreement is remarkably good. Consequently, this model was chosen to represent the elements of the vertical array for the purposes of the simulations studies.

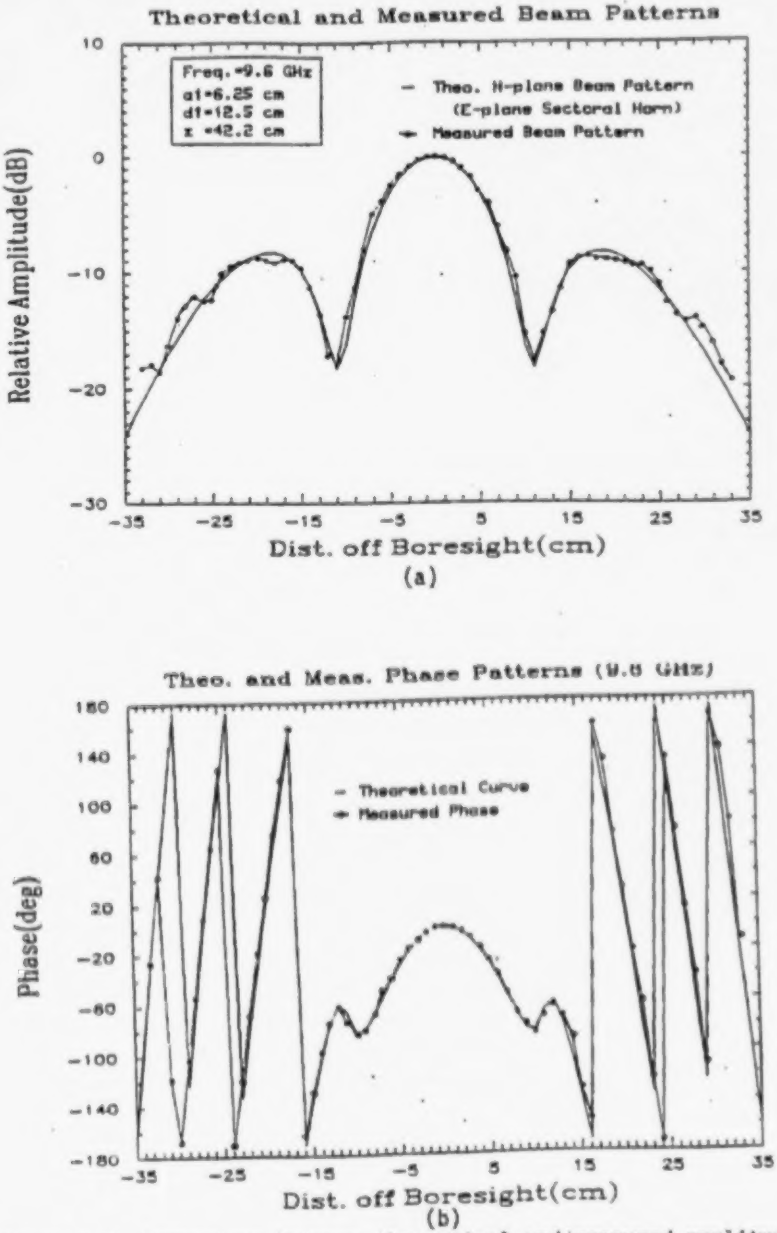
To obtain a slightly narrower horizontal beam pattern than could otherwise be obtained with the actual physical parameters, it was necessary to change the effective width and length of the horn-pairs. Therefore, although the height of each horn face was kept at 6.25 cm, the length was changed from 12.5 cm to 25 cm and the width was changed from 4.0 cm to 10.0 cm. The resulting horizontal beam patterns are shown in Figure 3.9. These changes have very little effect on the elevation beam patterns.

The software subroutine used to obtain the beam patterns for the main-beam array was named BEAMPAT1.FOR. A listing of the source code for this subroutine is included in Appendix D. The subroutine was written in VAX Fortran 77 and is called as follows:

```
CALL BEAMPAT1(HRX,HTARG,RT,FREQ,SIGD,SIGI,THETA)
```

where

HRX = input height of the receiver element
HTARG= input height of the radiation source
RT = input horizontal distance between source and receiver
FREQ = input frequency of the radiation source in GHz
SIGI = complex output signal representing the beam pattern of the indirect (reflected) beam.
SIGD = complex output signal representing the beam pattern of the direct beam.
THETA= input azimuthal angle of radiation source off boresight



(a)

(b)

Figure 3.7 Comparison between theoretical and measured amplitude and phase patterns for sectoral horn geometry at 9.6 GHz

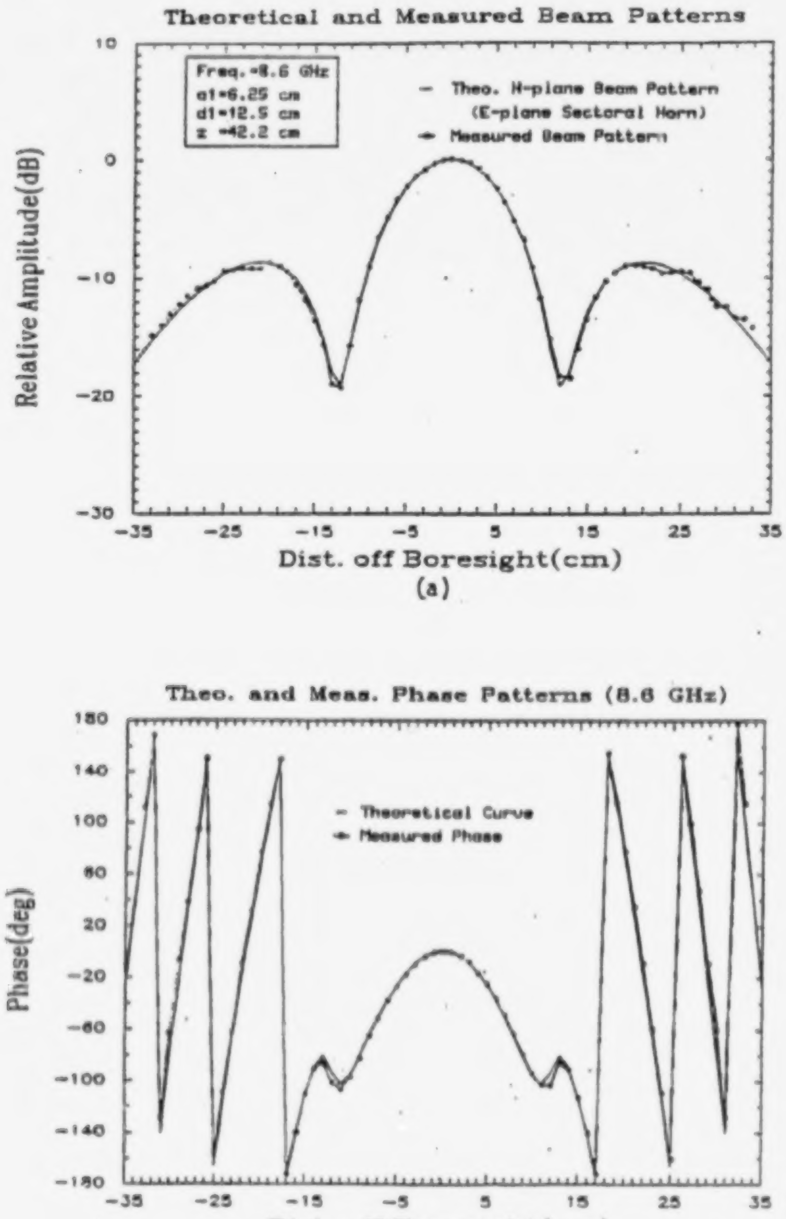


Figure 3.8 Comparison between theoretical and measured amplitude and phase patterns assuming sectoral horn geometry at 8.6 GHz

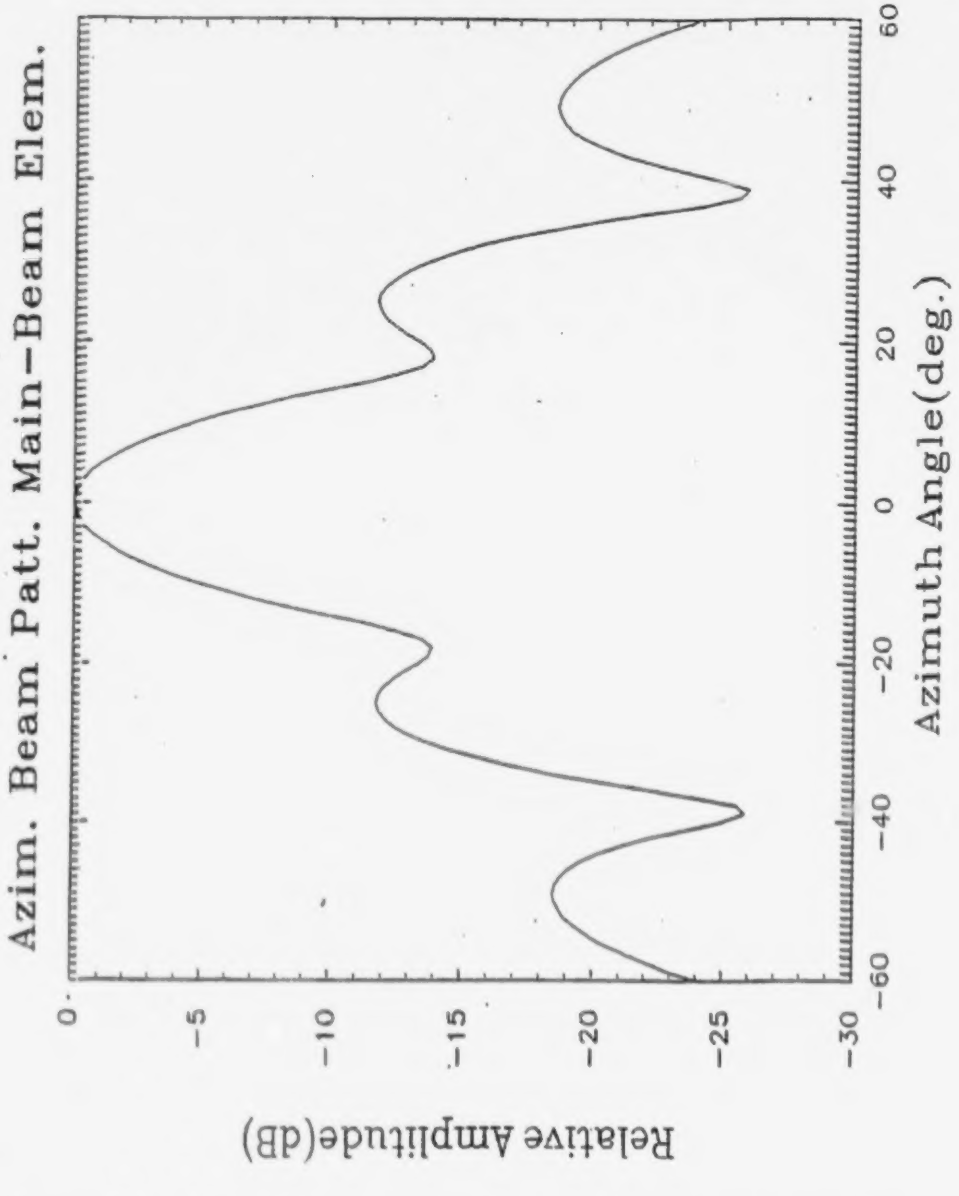


Figure 3.9 Azimuthal beam pattern for geometry used in simulations

A similar subroutine was created to determine the beam pattern of the horizontal SLC array, using the actual physical dimensions of the eight Narda 640 standard gain horns. This Fortran 77 subroutine named BEAMPAT2.FOR was called from the host routine as follows:

```
CALLBEAMPAT2(HRX,HTARG,RT,SIGD,SIGI,FREQ,THETA,I,SWH)
```

where I represents the SLC receiver element index, SWH (Significant Wave Height) represents a statistical measure of the surface roughness and the other seven parameters are the same as in BEAMPAT1. BEAMPAT1 and BEAMPAT2 both used subroutines named FRESNEL and DREFCO to calculate the Fresnel functions, and estimate the surface reflection coefficient respectively. The reflection coefficient was calculated assuming horizontal polarization. Source listings of these subroutines are also included in Appendix D. The subroutines BEAMPAT1 and BEAMPAT2 were used to generate the the main-beam and SLC array amplitude patterns shown in Figures 3.10 to 3.14. These plots show the multipath beam patterns for 8.6 and 9.6 GHz at a range of 1.0 km for main-beam receiver heights of 10, 20, 30, 40 and 50 m respectively (note: here the receiver height refers to the height of the bottom element above the reflecting surface). Combining the beams from the direct and indirect paths resulted in the multipath beam patterns shown. The vertical line in each plot indicates the height at the bottom element of the main-beam array. These plots imply that multipath could have significant adverse effects, not just on target tracking efficiency (eg. since the maximum of the beam pattern no longer coincides with the receiver height), but also on the ability of a source located off boresight to jam the desired signal. Multipath can cause the sidelobes to increase by several dB, and tends to fill in deep nulls in the beam pattern.

Similar beam pattern plots were generated for the SLC array for an array height of 10 metres, target height of 5 metres and a SWH of 1.0 metre. These plots are shown in Figure 3.15. It can be seen from these plots that the multipath has little effect on the azimuthal beam pattern.

The program created for simulating the radar signals received by a system such as that shown in Figure 3.2 was named SIMSLCMP.FOR. This program used the BEAMPAT1 and BEAMPAT2 subroutines to calculate a simulated signal that could be input to the sidelobe cancellation routine to do sensitivity studies of the SLC algorithm. This program had the ability to simulate the possible effects of simple multipath interference. A source listing of this program is included in Appendix D.

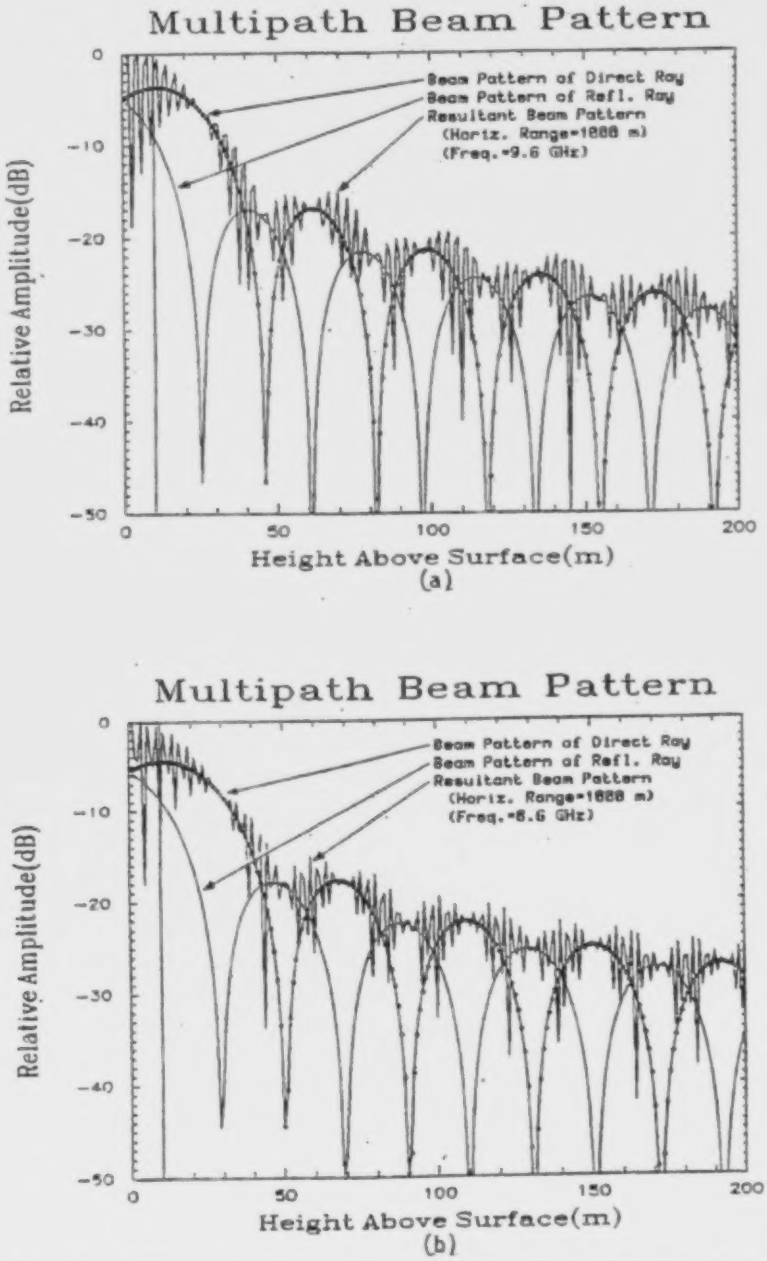


Figure 3.10 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 10 m above the reflecting surface.

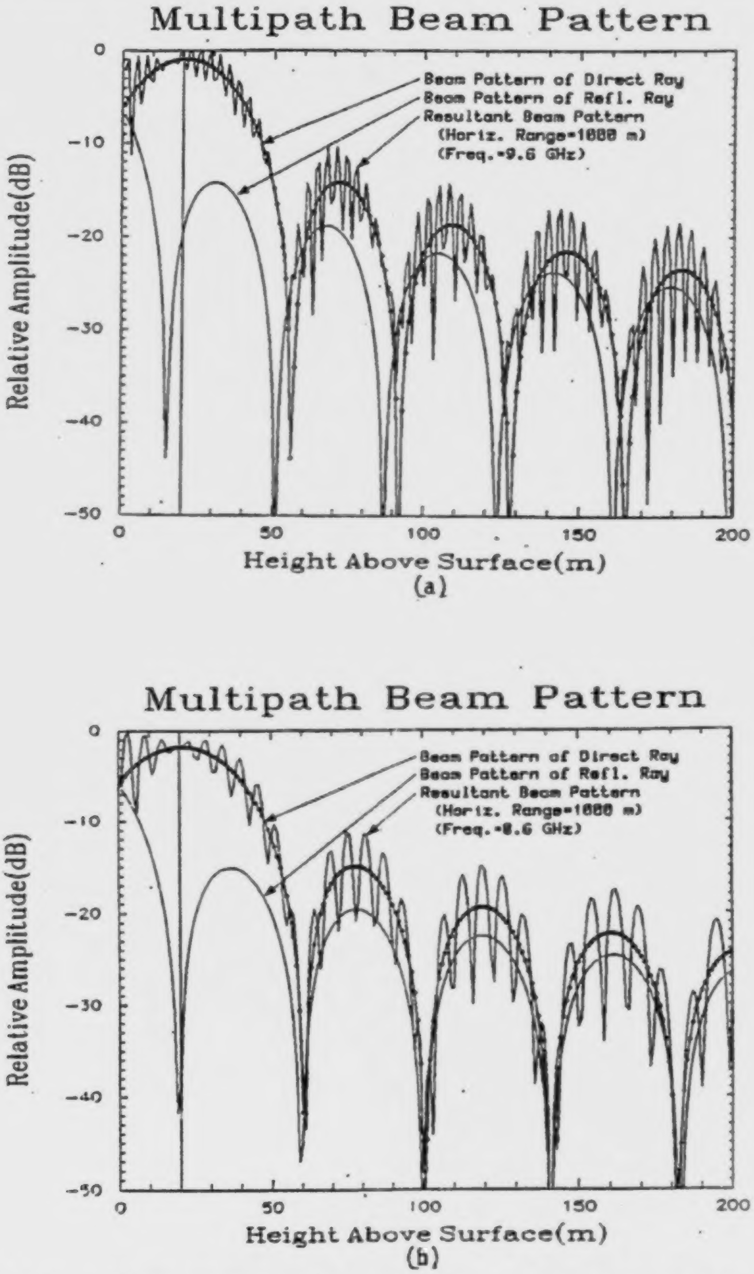


Figure 3.11 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 20 m above the reflecting surface.

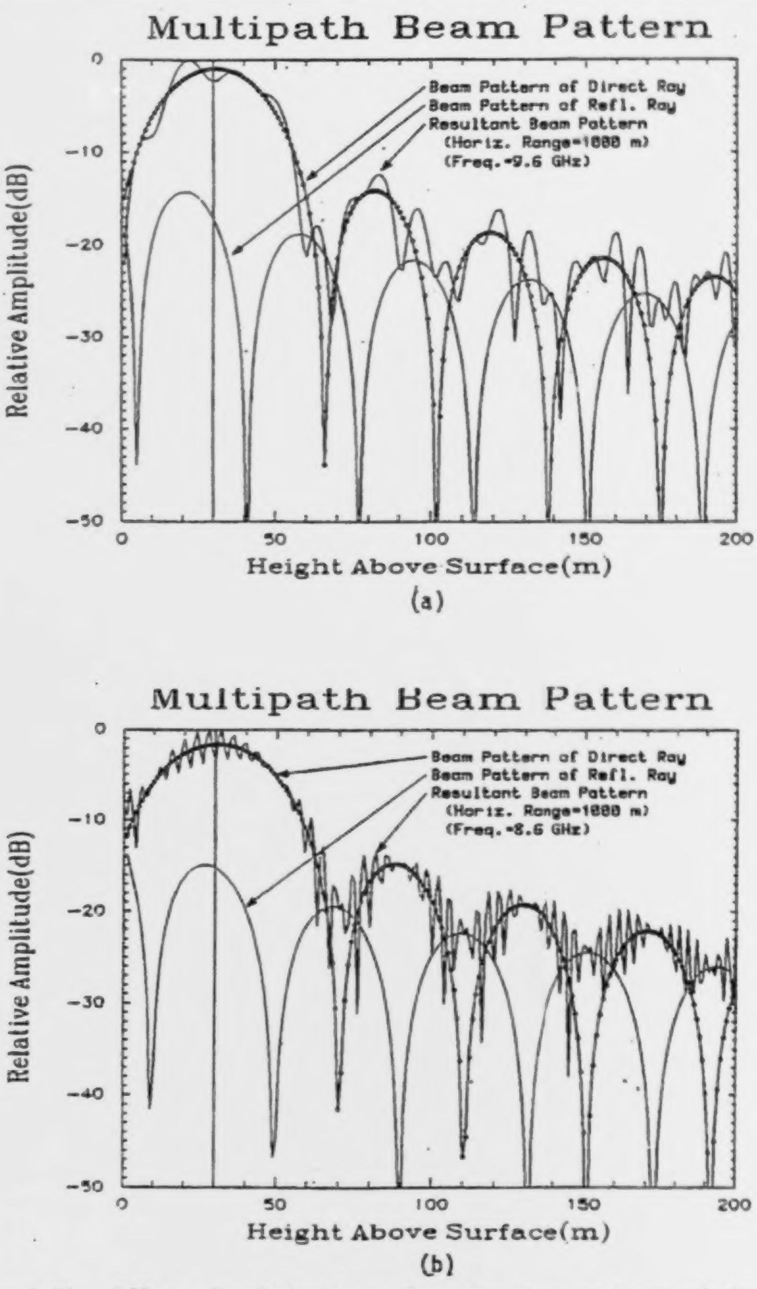
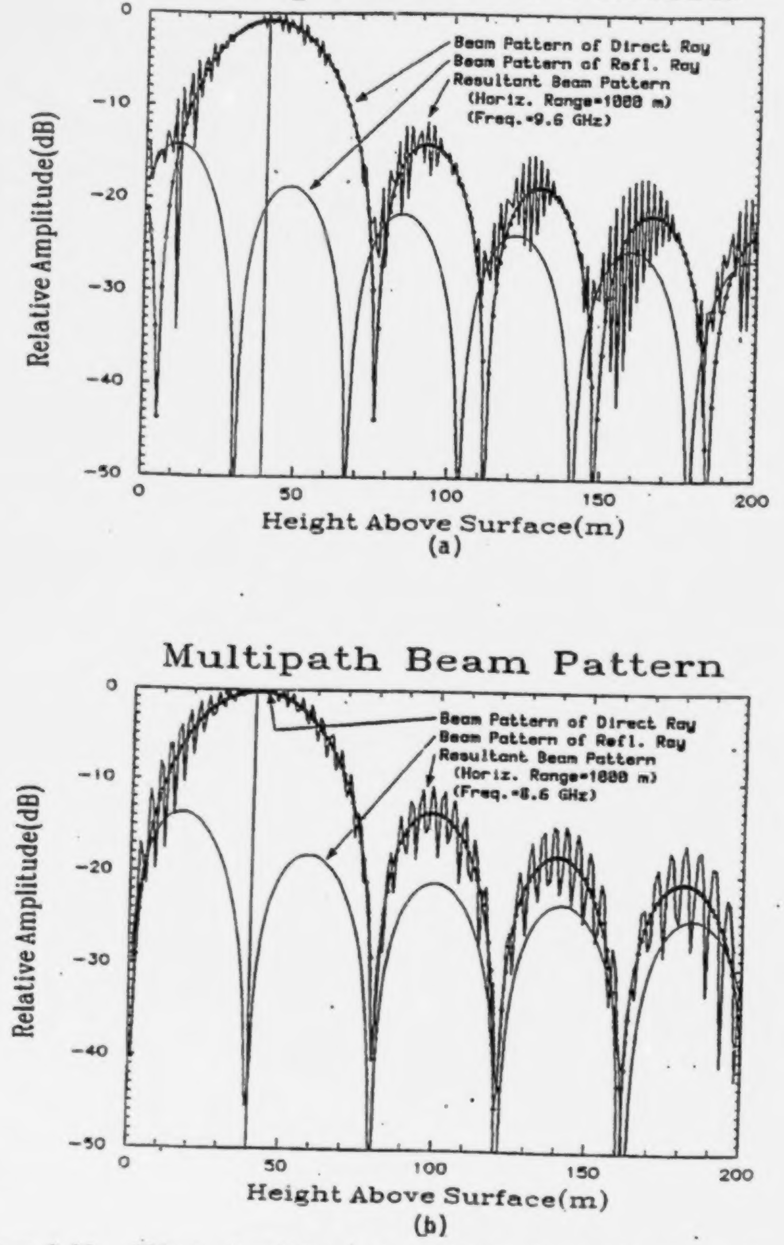


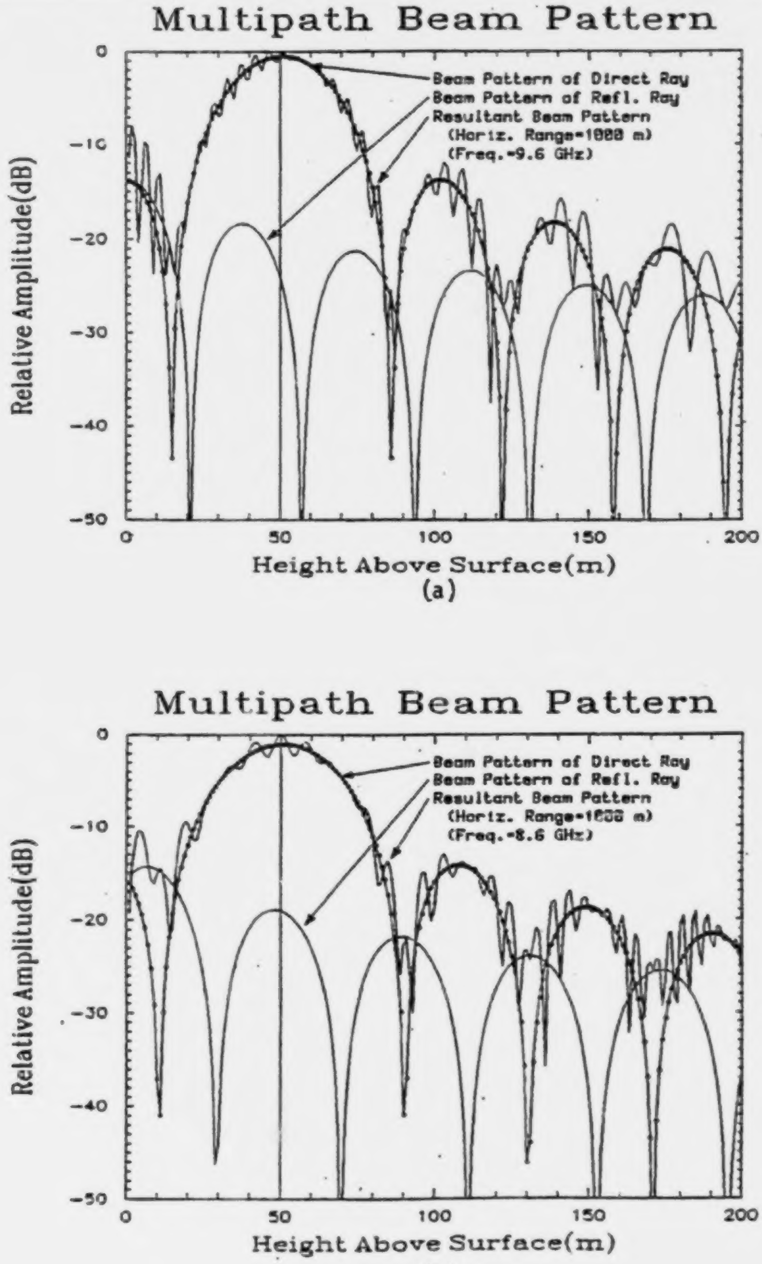
Figure 3.12 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 30 m above the reflecting surface.



(a)

(b)

Figure 3.13 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 40 m above the reflecting surface.



(a)

(b)

Figure 3.14 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 50 m above the reflecting surface.

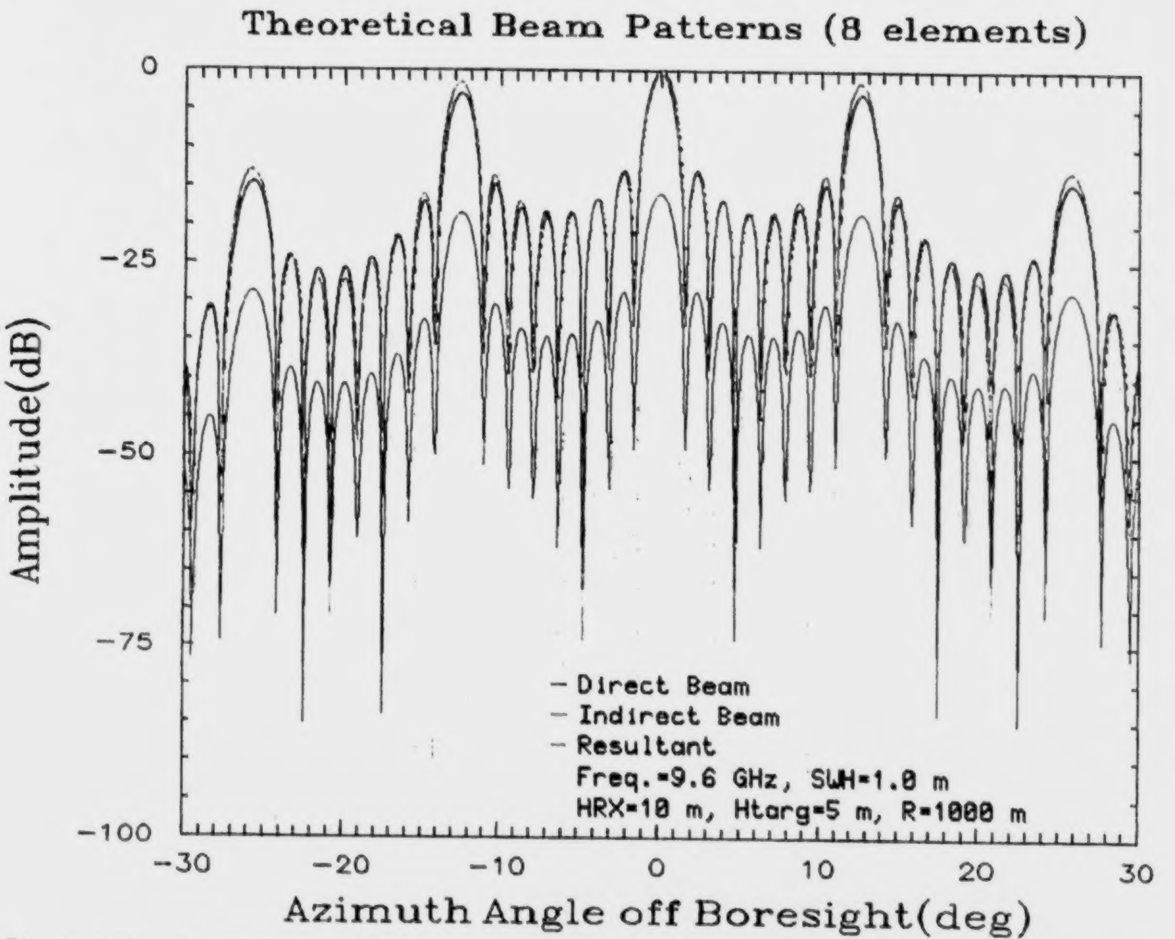


Figure 3.15 Theoretical azimuthal beam patterns for the simulated 8 element horizontal array showing the effect of multipath, assuming a significant wave height of 1.0 m

3.2 Task 1b) Coding and Testing of Sidelobe Cancellation Software

A simple sidelobe cancellation algorithm was supplied by the Scientific Authority which was coded, and tested using simulated and real experimental data. A brief description of the algorithm is given in Appendix F following similar algorithms elsewhere (eg.[3],[4]). The program, named MYSLC.FOR, was written in VAX Fortran 77 and installed on the microVAX of the Surface Radar Section at DREO. This software made use of the FPS5200 array processor to speed up the numeric processing (eg. calculation of numerous 2048 point FFTs). A source code listing of this program is included in Appendix D. A similar program was written in NDP Fortran 77 for use on a PC386 in case the AP was being used, or to enable it to be used during experiments at Area 5. This second program was seldom used because the AP version ran several times faster.

Figures 3.16 a) to d) show the effects of varying the signal to noise ratio (SNR) for the SLC array while keeping the SNR of the main-beam array constant. Conversely, Figures 3.17 a) to d) show the effect of varying the main-beam SNR while keeping the SLC SNR constant. In all of these plots the height of the receiver, jammer and target were set at 10,15 and 20 feet respectively, the range of the target and jammer were 16000 and 7900 metres respectively and the relative azimuth of the target and jammer with respect to the boresight was 0 and 45 degrees respectively. Also, in these four cases, there was assumed to be no multipath interference. Figures 3.18 a) to d) and Figures 3.19 a) to d) correspond to Figures 3.16 and 3.17 respectively but with simple multipath included. In these scenarios, the reflecting surface was assumed to be perfectly smooth (SWH=0) to demonstrate the largest possible effect, and a perfectly flat earth was also assumed for simplicity. As a consequence of the geometry, and the model used to simulate the data, the total signal strengths for the target and jammer in the main-beam array and the SLC array respectively are given in table 3.2.1.

Table 3.2.1

	Without Multipath	With Multipath
MT	-3.1 dB	-7.2 dB
MJ	11.3 dB	16.4 dB
ST	1.5 dB	7.1 dB
SJ	21.3 dB	26.7 dB

MT = total main-beam target power
MJ = total main-beam jammer power
ST = total SLC target power
SJ = total SLC jammer power

Table 3.2.2

MT/MN (dB)	MJ/MN (dB)	ST/SN (dB)	SJ/SN (dB)	Figure	SNR1 (dB)	SNR2 (dB)	IF (dB)
24.9	39.3	29.5	49.3	3.17 a)	1.2	17	16
24.9	39.3	15.5	35.3	3.16 a)	"	17	16
24.9	39.3	9.5	29.3	3.16 b)	"	16	15
24.9	39.3	3.5	23.3	3.16 c)	"	13	12
24.9	39.3	-4.5	15.3	3.16 d)	"	7	6
18.9	33.3	29.5	49.3	3.17 b)	"	12	11
10.9	25.3	29.5	49.3	3.17 c)	"	5	4
4.9	19.3	29.5	49.3	3.17 d)	"	2	1

MN = total main-beam noise power
MT = total target power in main-beam array
MJ = total jammer power in main-beam array
SN = total SLC noise power
ST = total target power in SLC array
SJ = total jammer power in SLC array
SNR1 = total (jammer+signal+noise)/(jammer+noise) ratio before sidelobe cancellation
SNR2 = total ouput signal to noise ratio after cancellation
IF = improvement factor (SNR2-SNR1)
Note : the above results were obtained by averaging over 256 points

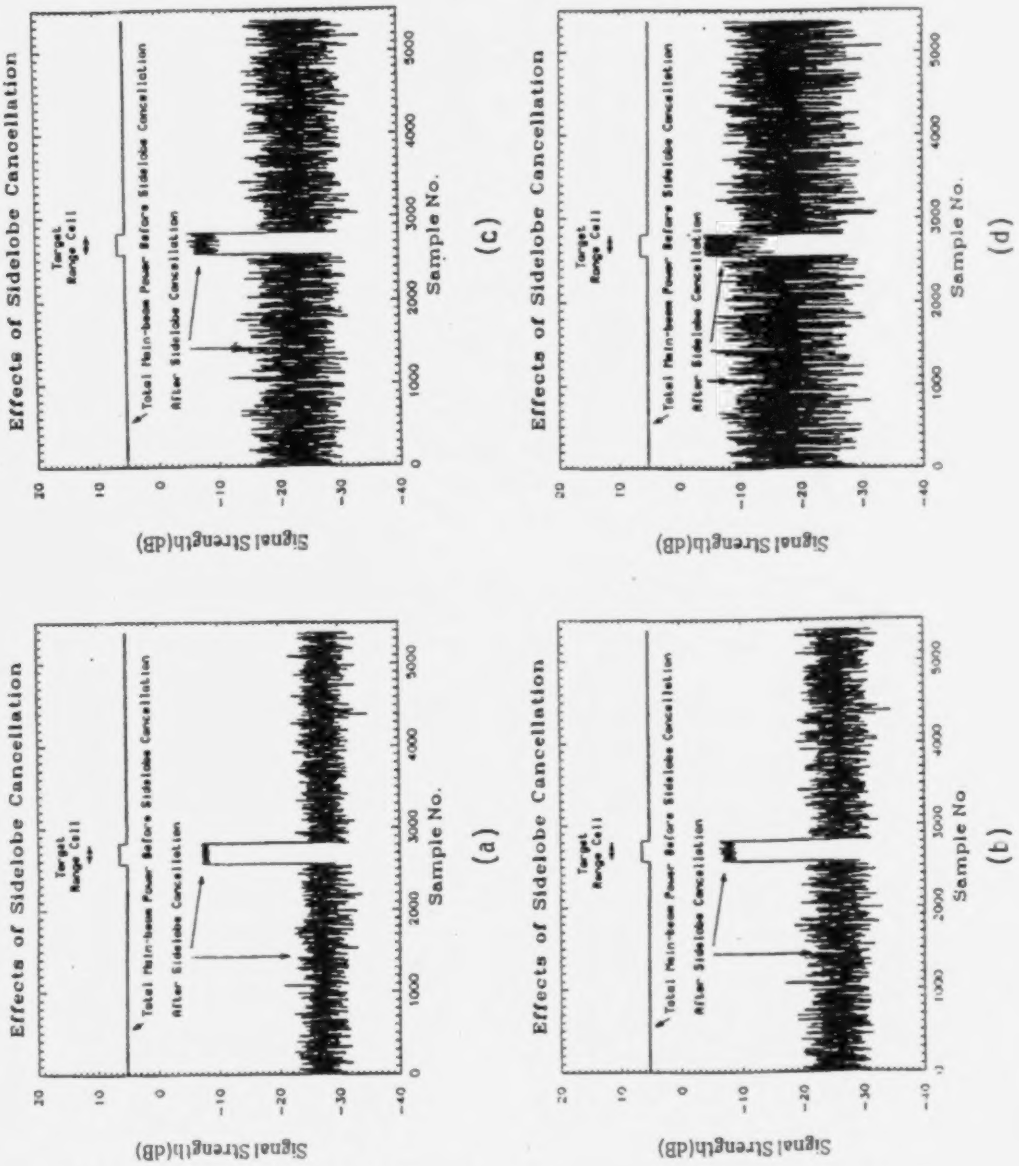


Figure 3.16 Plots (a) to (d) show the improvement in the effective output signal to noise ratio for different noise levels in the SLC array. Table 3.2.2 gives a description of each plot in terms of the various input signal to noise ratios, and gives an estimate of the improvement.

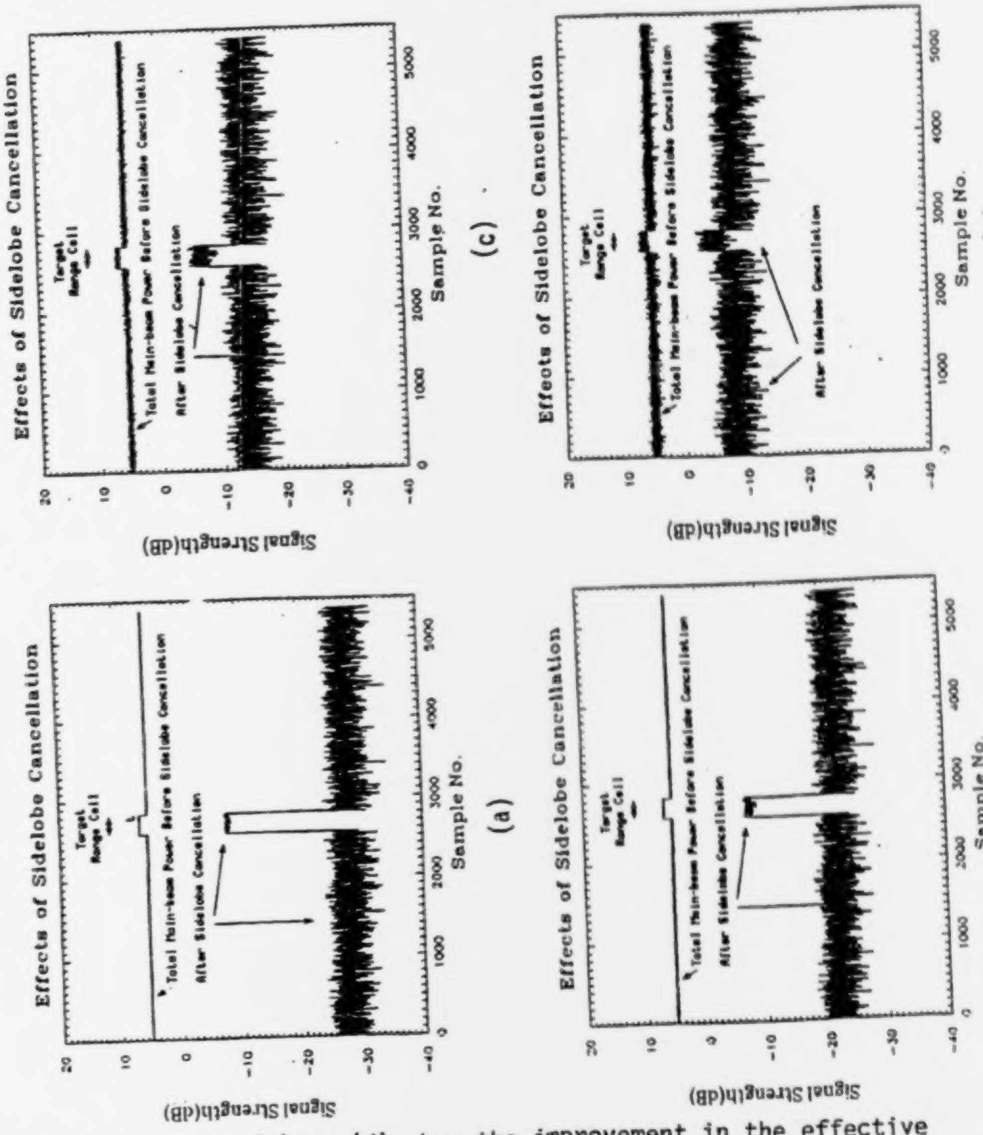


Figure 3.17 Plots (a) to (d) show the improvement in the effective output signal to noise ratio for different noise levels in the main-beam array. Table 3.2.2 gives a description of each plot in terms of the various input signal to noise ratios, and gives an estimate of the improvement.

Table 3.2.3

MT/MN (dB)	MJ/MN (dB)	ST/SN (dB)	SJ/SN (dB)	Figure	SNR1 (dB)	SNR2 (dB)	IF (dB)
20.8	44.4	35.1	54.7	3.19 a)	0.4	17	17
20.8	44.4	21.1	40.7	3.18 a)	"	17	17
20.8	44.4	15.1	34.7	3.18 b)	"	16	16
20.8	44.4	9.0	28.6	3.18 c)	"	13	13
20.8	44.4	1.1	20.7	3.18 d)	"	7	7
14.7	38.3	35.1	54.7	3.19 b)	"	12	12
6.8	30.4	35.1	54.7	3.19 c)	"	5	5
-0.8	24.4	35.1	54.7	3.19 d)	"	2	2

MN = total main-beam noise power
MT = total target power in main-beam array
MJ = total jammer power in main-beam array
SN = total SLC noise power
ST = total target power in SLC array
SJ = total jammer power in SLC array
SNR1 = total (signal+jammer+noise) to (jammer+noise) ratio before cancellation
SNR2 = output signal to noise ratio after cancellation
IF = improvement factor (SNR2-SNR1)
Note: above results were obtained by averaging over 256 points

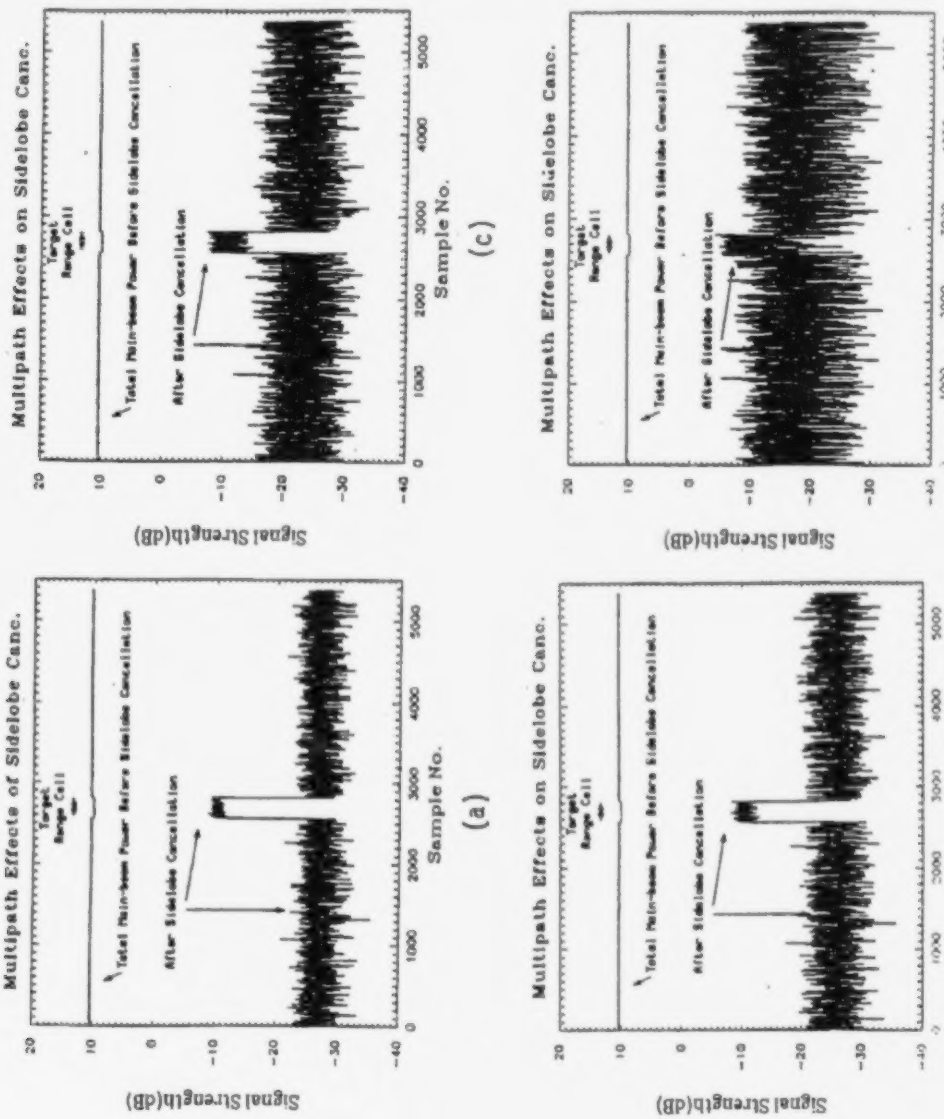


Figure 3.18 Plots (a) to (d) show the improvement in the effective output signal to noise ratio for different noise levels in the SLC array. Table 3.2.3 gives a description of each plot in terms of the various input signal to noise ratios and gives an estimate of the improvement. Each of the above results was obtained assuming multipath interference.

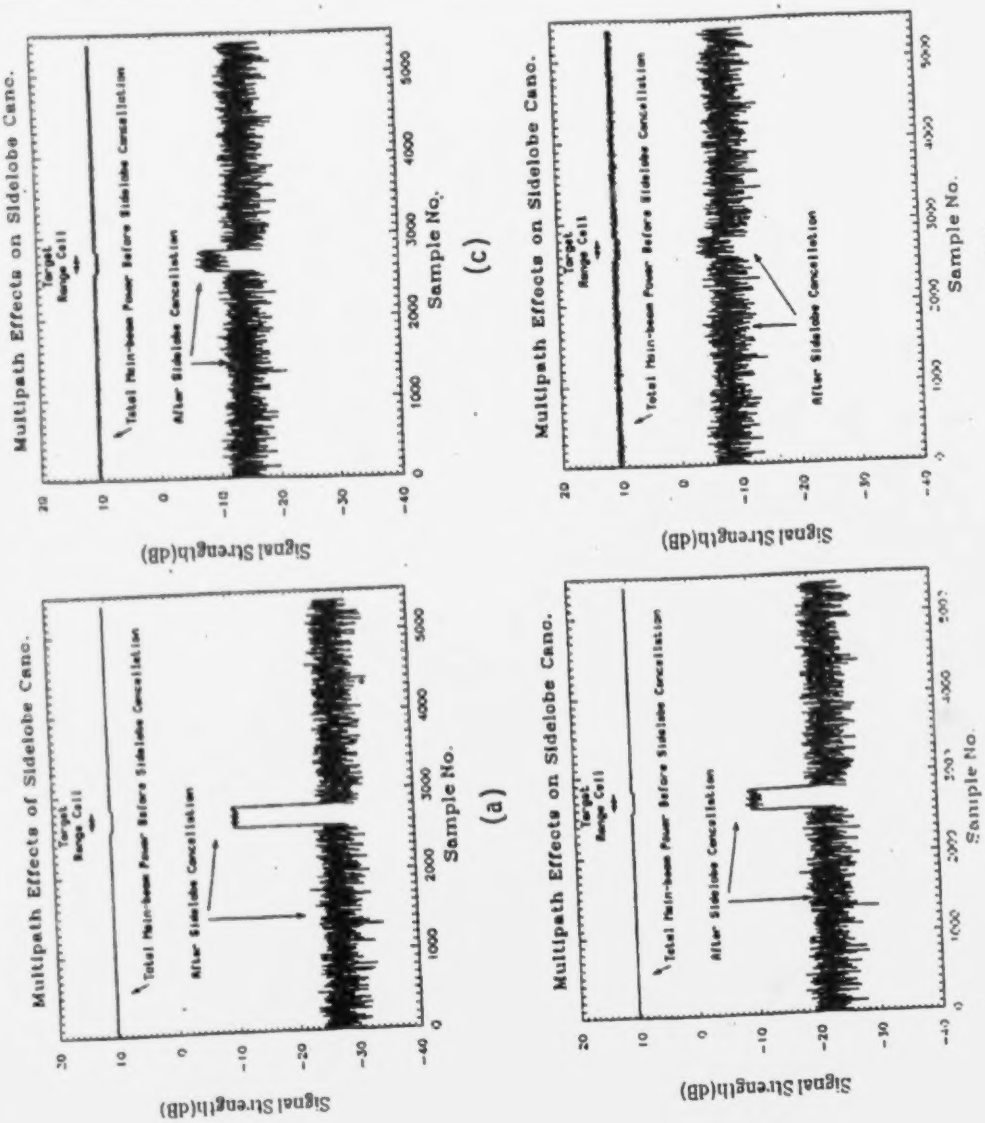


Figure 3.19 Plots (a) to (d) show the improvement in the effective output signal to noise ratio for different noise levels in the Main-beam array. Table 3.2.3 gives a description of each plot in terms of the various input signal to noise ratios and gives an estimate of the improvement. Each plot was done assuming multipath interference was present.

Tables 3.2.2 and 3.2.3 give a breakdown of some of the important aspects of Figures 3.16 to 3.19 in terms of signal to noise ratio. It is interesting to note that for this particular scenario, the output signal to noise ratio was independent of the presence of simple multipath interference; however, the improvement factor is slightly different because of multipath. It should be noted that in the above cases the noise power was assumed to be the same for each channel within an array.

3.3 Task 1c) Data Analysis and Testing the Effectiveness of the Sidelobe Canceller Software

In order to analyse the effectiveness of the sidelobe cancellation algorithm on real experimental data, the data first had to be reformatted for use by the SLC software (MYSLC). Two lengthy programs named SLCRD1 and SLCRD2 were created to read and reformat the data from the spring and fall trials respectively. These programs had to read the data and pre-process it to correct as many hardware created errors as possible before other analysis could continue. Some typical errors that occurred in the data were: spurious signal spikes, insertions of one or more extraneous data words into the data, changing or altering data flag words etc. Some of these errors were sufficiently benign that general correction software was included in the programs to remedy them; however, in many cases the errors were random enough that they required inserting file-specific code to do the corrections. This was often time consuming and resulted in the two routines SLCRD1 and SLCRD2 being several thousand lines long each. For this reason their source listings will not be included in this report but will be presented directly to the Scientific Authority along with a description of their usage. The most significant difference between the two software packages is that the hexadecimal data flag words denoting the end of the SLC data records and the beginning of the main-beam data were changed from 'f0fe' and 'f1fe' to 'f0fd' and 'f1fd' respectively. The original software was written by D. Brookes with a siginficant portion of the file-specific code inserted by A. Wilkinson.

The two software packages mentioned above were used to read data logger files and format the output data so that it could be used by the sidelobe canceller program. The programs produced 10 output files. The names of these files along with a brief description of each follows:

errfile.dat - this data file contains a listing of the locations of errors encountered in the data logger file, and corrected.

rngfile.dat - contains a record of each on-target and off-target range encountered in the file

htraw.dat - contains high frequency on-target main-beam data

htslc.data - contains high frequency on-target slc data

hoslc.dat - contains high frequency off-target slc data

horaw.dat - contains high frequency off-target main-beam data

ltraw.dat - contains low frequency on-target main-beam data

ltslc.data - contains low frequency on-target slc data

loraw.dat - contains low frequency off-target main-beam data

loslc.dat - contains low frequency off-target slc data

Once the data had been reformatted it was also subjected to tests to determine the data quality; for example, determine if any extraneous noise sources were present such as 120 hertz interference, or if there appeared to be any I-Q phase and/or amplitude mismatches. These problems could be identified by doing sequential FFTs of the data. Any 120 Hz interference would show up as peaks at the appropriate position on the plots. Also, if there was any movement of the target (or beacon), I-Q phase and/or amplitude mismatches would show up as negative frequency 'image' peaks of the Doppler shifted target signal on the FFT plots. A program called PLOTSLCFFT.FOR was created, using graphics subroutines developed at DREO, to plot up to 9 sequential FFT plots on a single page. This made it more efficient for compiling the results for future use. The data from the March 1993 trials was subjected to this analysis and the results were compiled for the Scientific Authority. Figures 3.20 to 3.23 are representative examples of 1024 point FFT plots for run 7 of March 4, 1993. Each set of plots, in order, represents the high frequency data for on-target main-beam, off-target main-beam, on-target SLC and off-target SLC data respectively. The vertical axis on each plot represents the signal strength in decibels, from -90 to +10 dB, and the horizontal axis is the Doppler bin number from -512 to 512. The zero frequency doppler bin, i.e. DC, is indicated by a central vertical bar at the top and bottom of each plot.

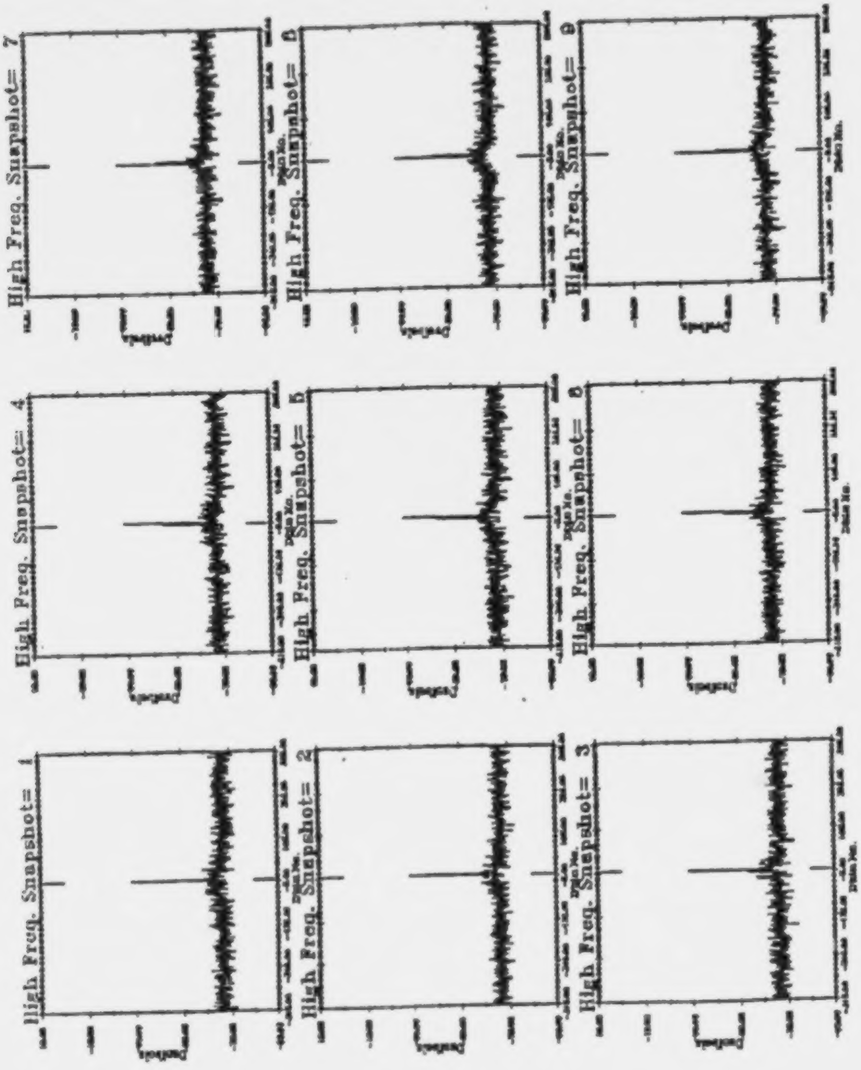


Figure 3.20 Sequential 1024 pont FFTs of contiguous (1024 point) data segments, for on-target, main-beam data from Run 7 March 4 1993

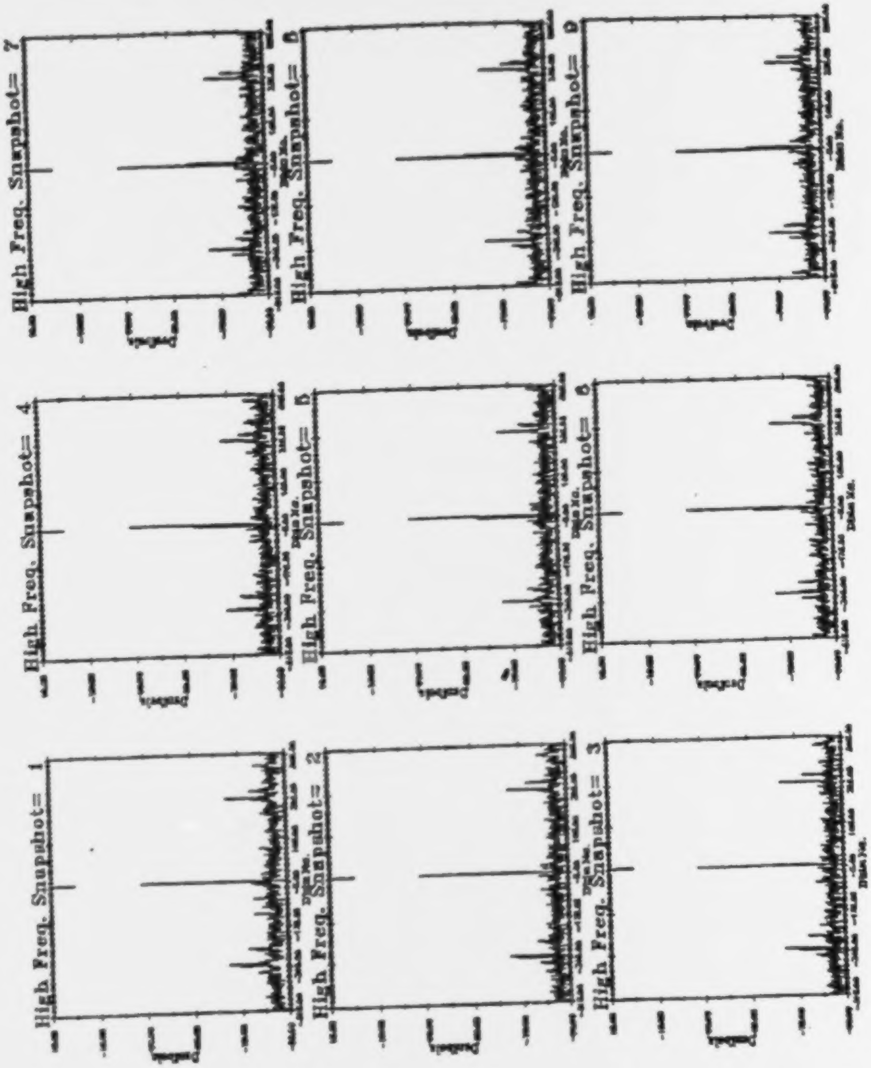


Figure 3.21 Sequential 1024 pont FFTs of contiguous (1024 point) data segments, for off-target, main-beam data from Run 7 March 4 1993

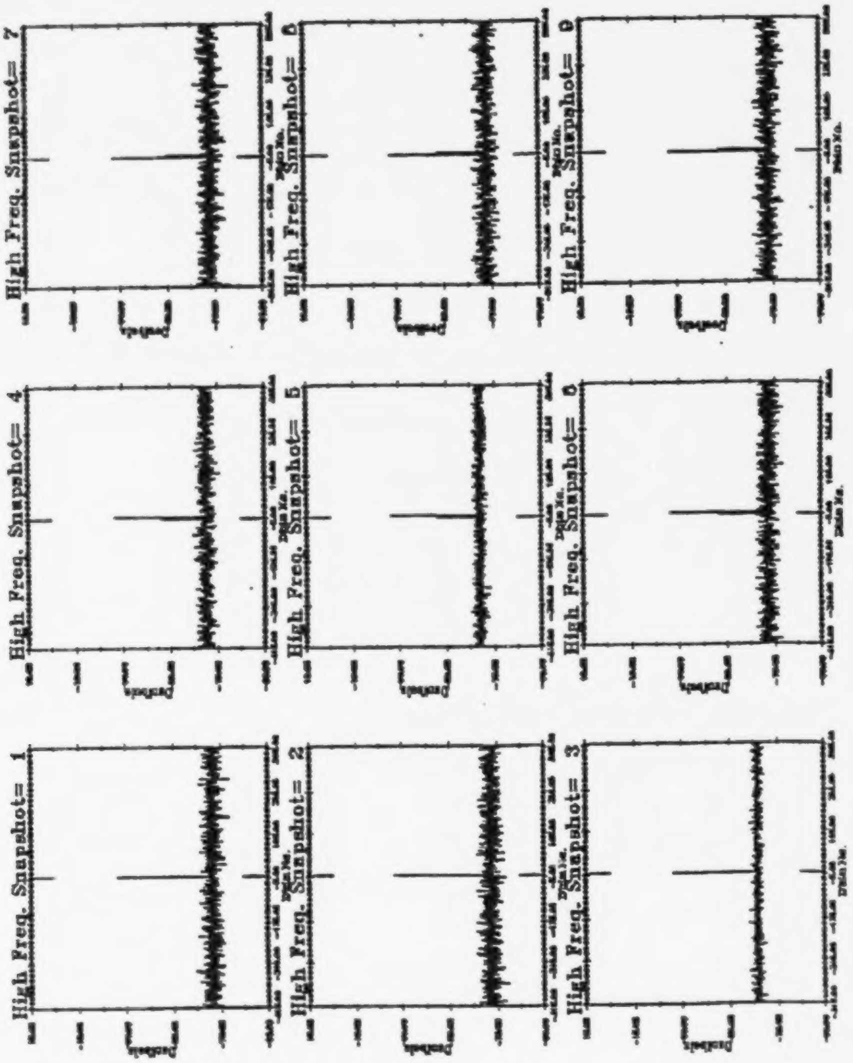


Figure 3.22 Sequential 1024 pont FFTs of contiguous (1024 point) data segments, for on-target, SLC array data from Run 7 March 4 1993

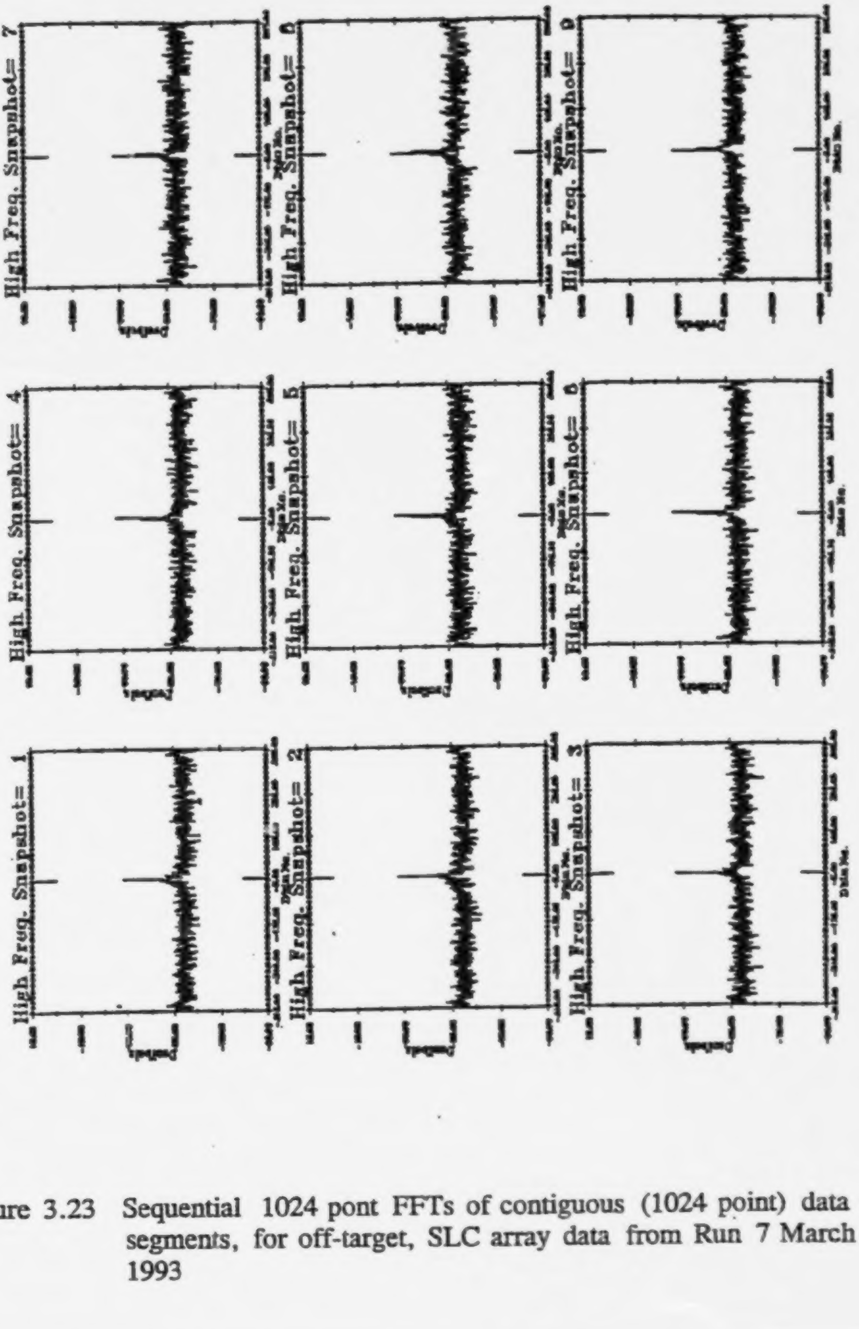


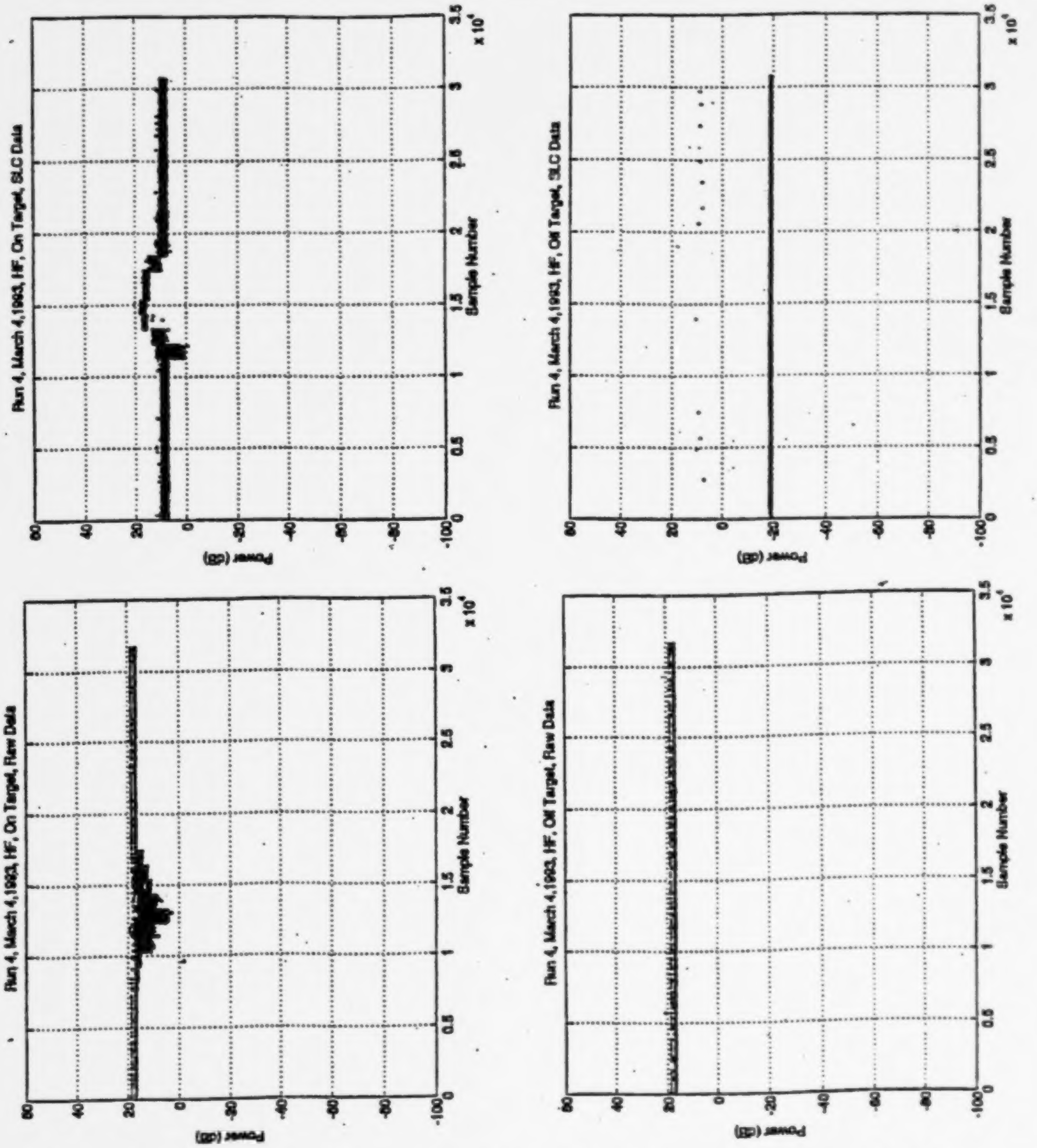
Figure 3.23 Sequential 1024 pont FFTs of contiguous (1024 point) data segments, for off-target, SLC array data from Run 7 March 4 1993

To determine if there were any peculiarities of the data in the time domain, a series of plots were created, for each file, of the of the total received power (in dB), the amplitude, and the phase. The amplitude and phase plots were only created for one representative receiver element of either array, to reduce the analysis to a reasonable level; these plots combined with the total power plots to produce more than 360 plots for just the spring trials alone. The formula for determining the total received power was:

$$\text{Power} = 10 \cdot \log_{10}\left(\Sigma_{n=1}^{n=8} (I_n^2 + Q_n^2)\right)$$

where I_n and Q_n were the in-phase and quadrature components of the signal for the nth receiver element. A series of representative plots were created for the high frequency on-target main-beam, off-target main-beam, on-target SLC, and off-target SLC data. The low frequency data was not included because only the high frequency was operational during the trials. Figures 3.25 to 3.27 are representative plots of the total received power, amplitude, and phase, respectively, for run 4 of March 4, 1993. Figures 3.28 to 3.30 are similar plots for run 11 of March 8, 1993. These two runs were both examples of data obtained using the SLC2 program (see section 5.0), of a corner reflector target being jammed by a beacon in a sidelobe of the receivers. Although the beacon was not powerful enough to drown out the very strong signal from the corner reflector, it did present an opportunity to see how well the sidelobe cancellation algorithm in MYSLC improved the signal to noise ratio as SLC2 stepped through the target range cell.

The results of the sample to sample analysis for run 4 and run 11 is shown in Figure 3.31 and 3.32 respectively. In Figure 3.33, the same results are repeated but with averaging over 1024 sample points and showing the range corresponding to each sample average. In each figure, the upper curve represents the total received power for the main-beam array, and the lower curve represents the sidelobe cancelled results. Figure 3.33 shows a 15-20 dB improvement in the total signal to noise ratio as a result of the sidelobe cancellation procedure.



Run 4, March 4,1993, HF, On Target, SLC Data

Run 4, March 4,1993, HF, Off Target, SLC Data

Run 4, March 4,1993, HF, On Target, Raw Data

Run 4, March 4,1993, HF, Off Target, Raw Data

Figure 3.25 Plots of total received power for high frequency on target main-beam (raw) and SLC arrays with corresponding off target cases for Run 4, March 4 1993

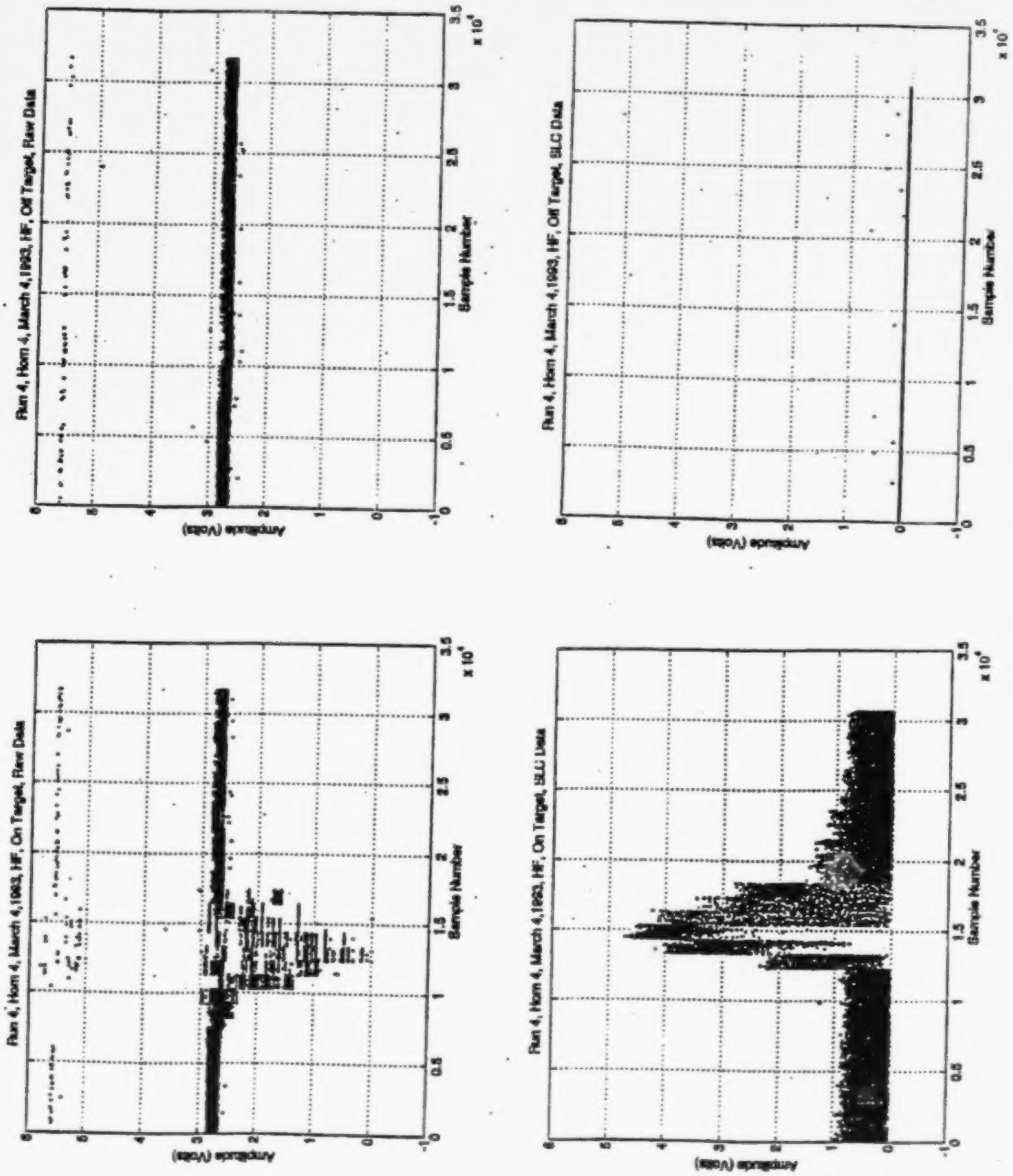


Figure 3.26 Plots of received signal amplitude from element 4 of the main-beam and SLC arrays, on and off target cases, for Run 4 March 4 1993

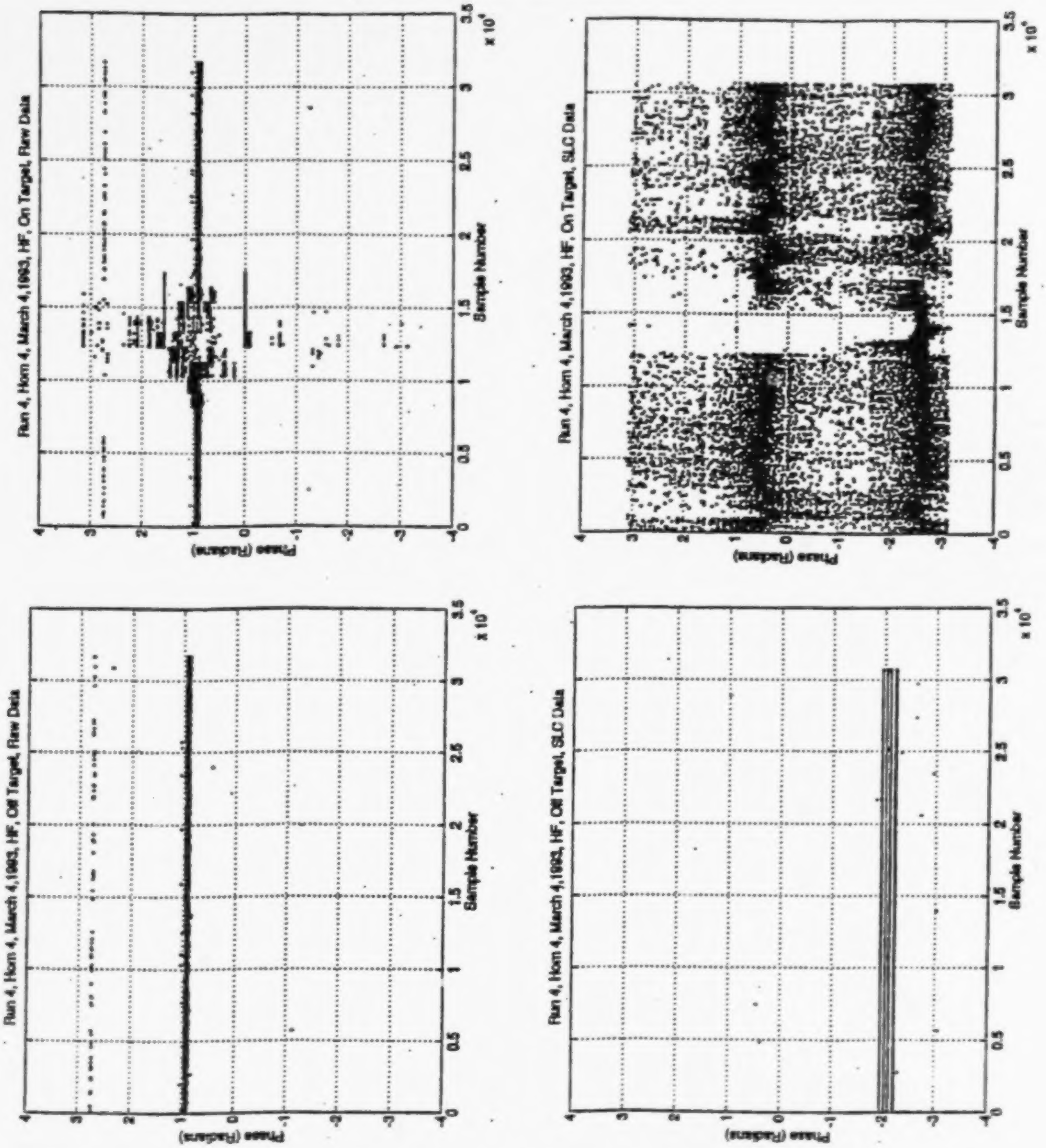


Figure 3.27 Plots of the phase of the received signal from element 4 of the main-beam and SLC arrays, on and off target cases, for Run 4 March 4 1993

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[1] AIT Corporation, November 1993

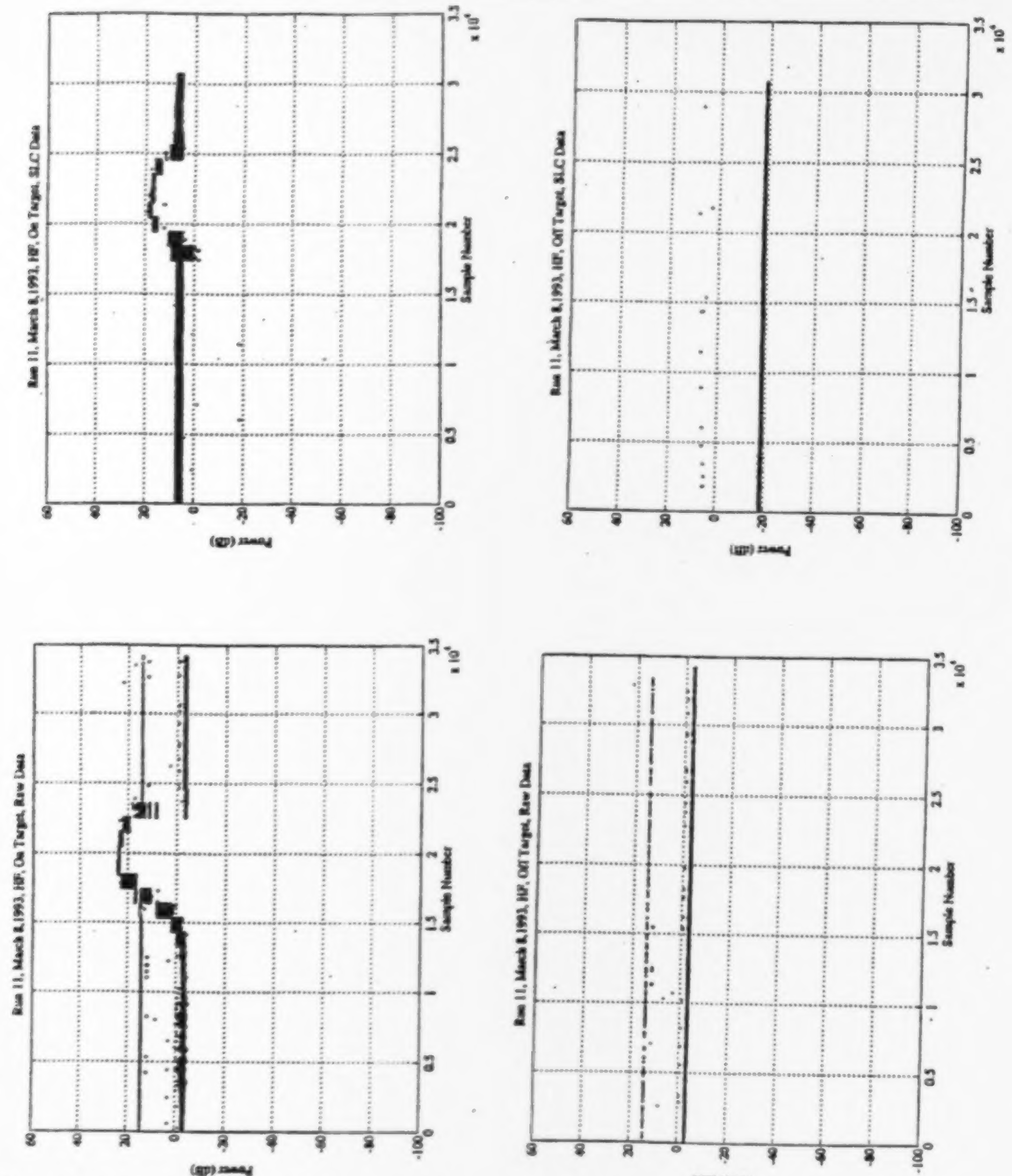


Figure 3.28 Plots of total received power for high frequency signals from the main-beam and SLC arrays, on and off target, for Run 11 March 8

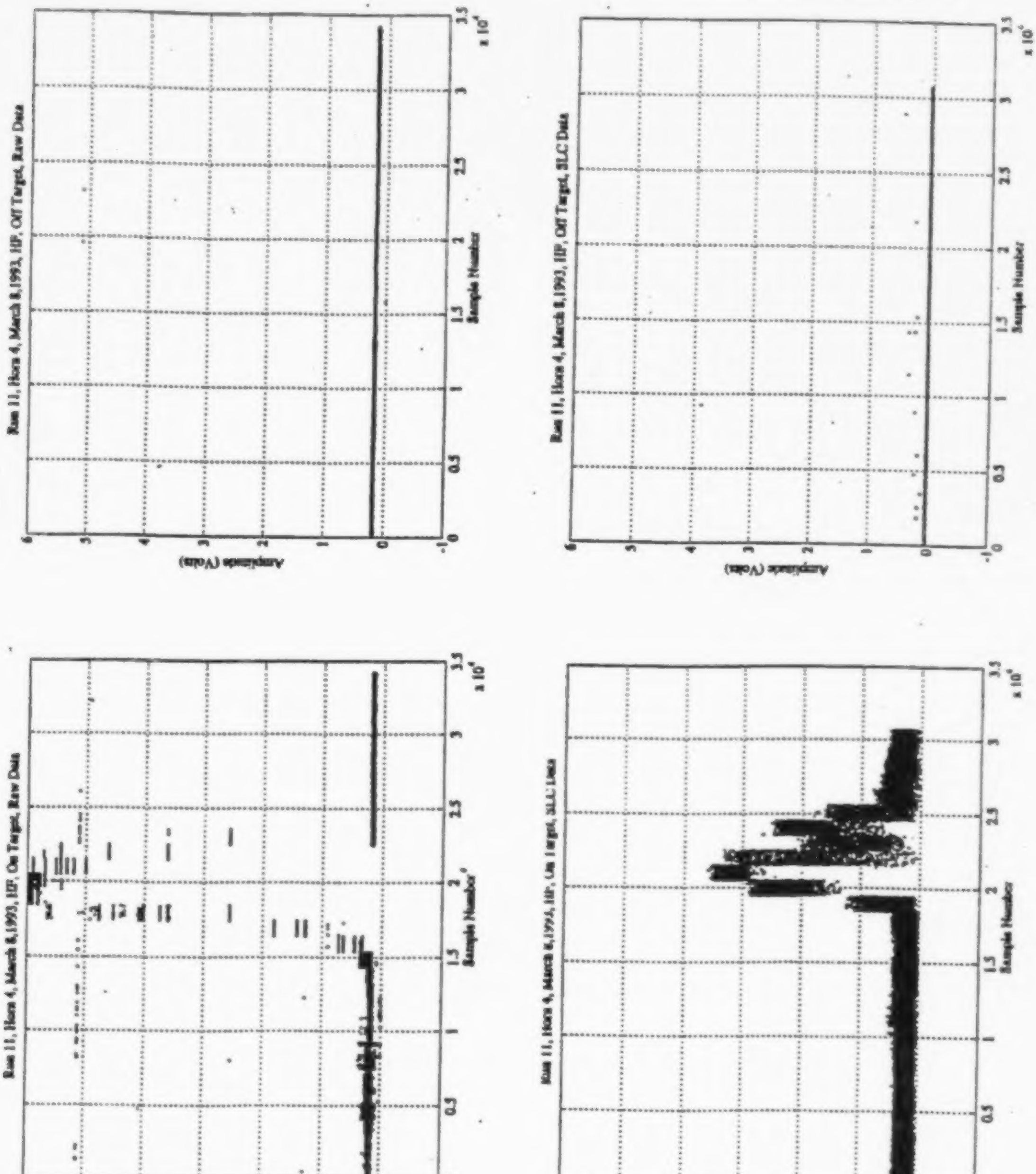


Figure 3.29 Plots of received signal amplitude from element 4 of the main-beam and SLC arrays, on and off target cases, for Run 11 March 8, 1993

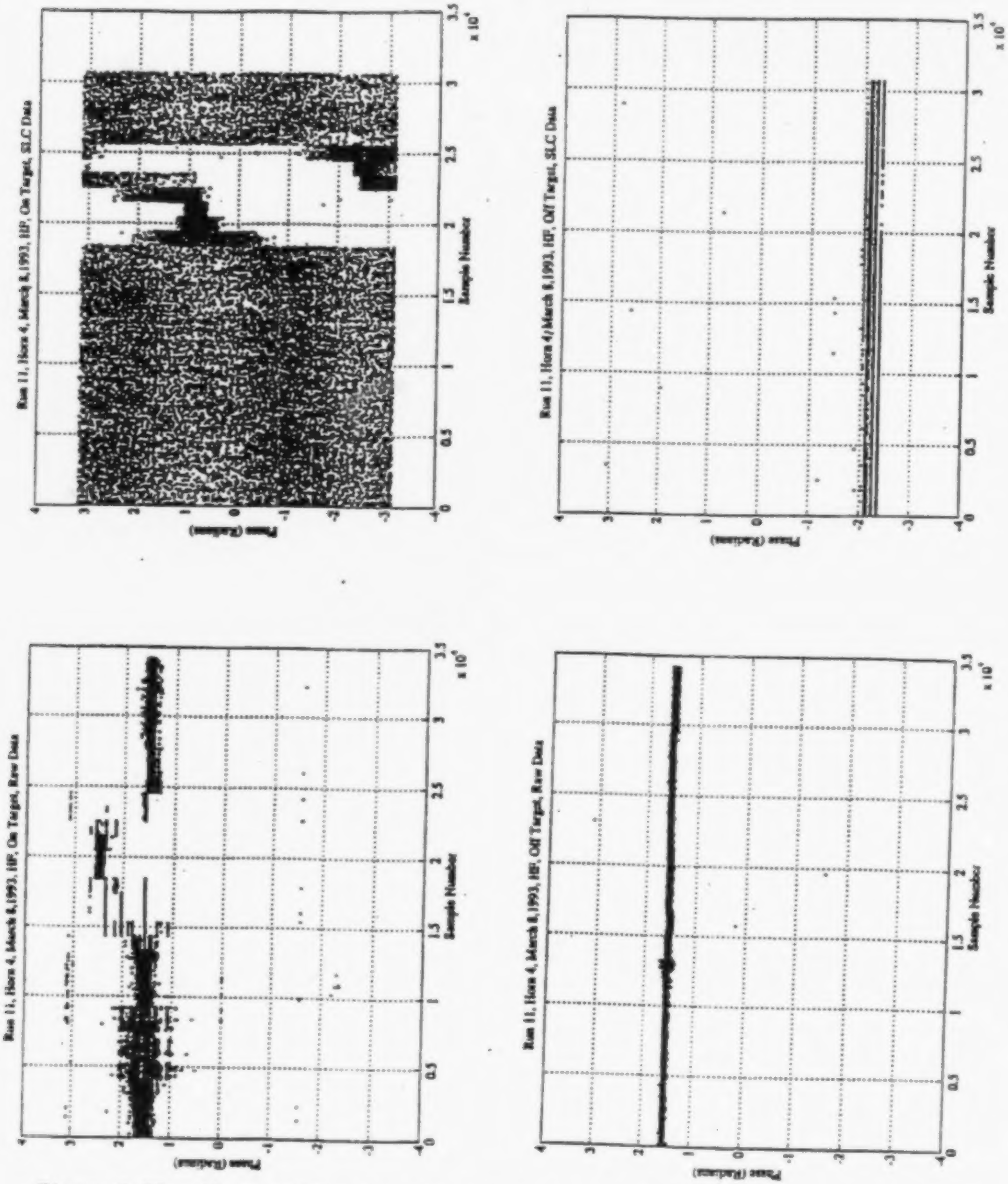


Figure 3.30 Plots of the phase of the received signal from element 4 of the main-beam and SLC arrays, on and off target,cases, for Run 11 March 8

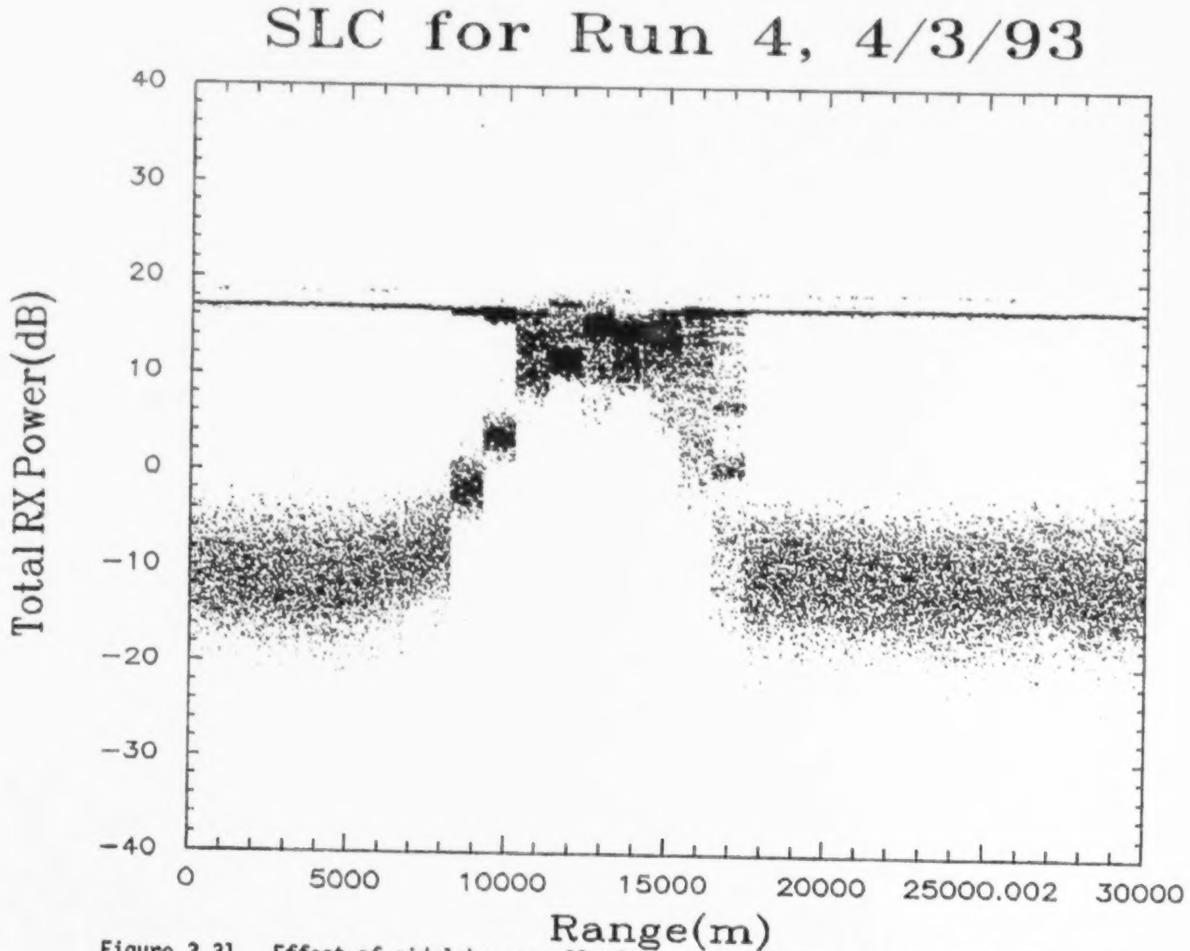


Figure 3.31 Effect of sidelobe cancellation on data from Run 4, March 4. The green indicates total received power before sidelobe cancellation and the red shows the results after sidelobe cancellation.

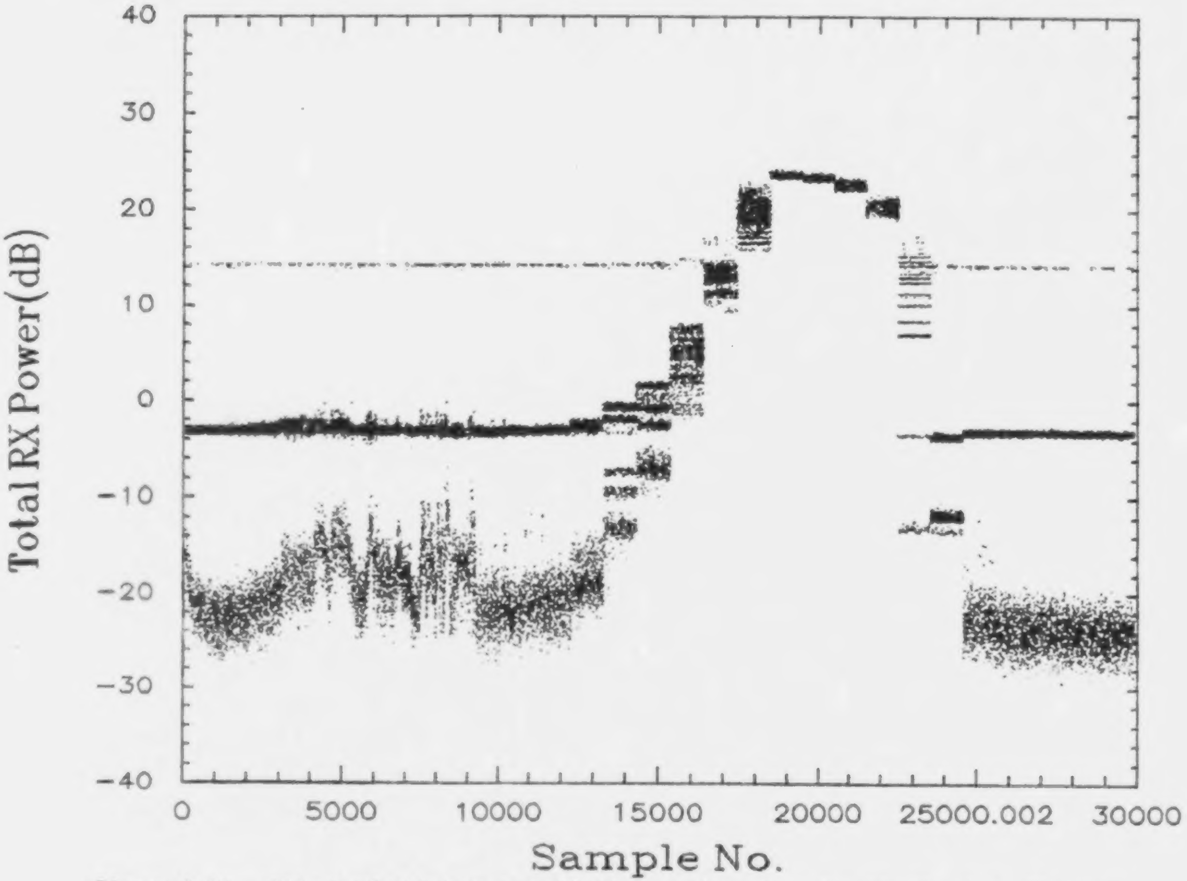
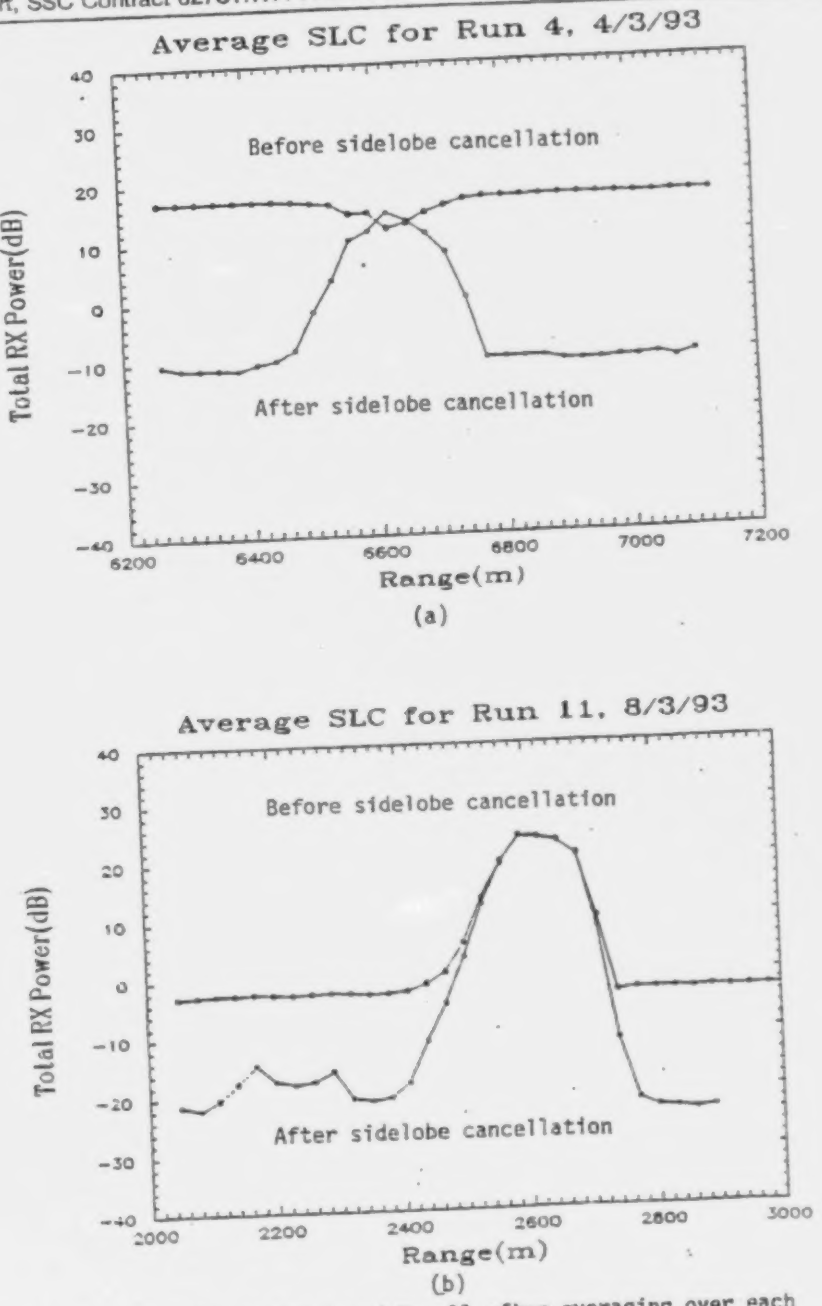


Figure 3.32 Effect of sidelobe cancellation on data from Run 11, March 8. The green indicates total received power before sidelobe cancellation and the red shows the results after sidelobe cancellation.



(a)

(b)

Figure 3.33 Results of Run 4 and Run 11 after averaging over each range cell (1024 data points) and plotting versus range

4.0 Monopulse Sensitivity to Array Tilt Analysis

As stated earlier, the original purpose of this task was to perform analyses of the effects of array tilt due to ships motion on monopulse performance in the presence of multipath, using a simple 2-dimensional antenna array model (something similar to the EARS for instance). However, over the course of the contract, a quite complex simulator named GENXDATA was developed to carry out some of these studies. The actual physical characteristics of the array under simulation are confidential, therefore limiting the amount of information that can be divulged in this report. This must be kept in mind while reading this section.

The GENXDATA software package was developed to generate the theoretical received signal amplitude and phase distribution across the 2 dimensional aperture based on the target to receiver geometry. The geometry of the array was determined and a file containing all of the heights and distances of each element of the array with respect to the centre of the array was generated.

The software was used to analyse the effect of array tilt on the standard phase comparison monopulse algorithm software. When the synthetic data produced by GENXDATA was used in the phase comparison monopulse the estimated target heights matched quite closely with the actual target heights.

GENXDATA was continually being modified to meet anticipated needs. The software is presently capable of being able to handle the following conditions: a) a target coming in off boresight, b) tapering of the receiver response using illumination functions provided by the Scientific Authority, c) electronically pointing the array in the direction of the target using azimuth and elevation steering directions to calculate a phase shift, and d) side tilt and tilt back of the array. The results produced by GENXDATA were analysed using MATLAB software, a useful mathematical analysis software package for the PC. and SUN Workstations.

At present, the tapering of the receiver response has been accomplished by using linear Taylor weighting for calculating the sum signal of the array, and Bayliss weighting for the difference signal. The Taylor and Bayliss [5] weighting have been incorporated into the simulator in such a way that they can be used for both azimuthal and elevation phase monopulse angle estimations. The effects of simple multipath has also been incorporated into the simulator for studying its effects on phase monopulse angle estimations in both the azimuthal and elevation directions.

The effects of combining data from multiple frequencies to reduce the angle estimation error in phase monopulse due to multipath interference has been studied for a variety of scenarios. The results of these studies are to be published in two internal DREO reports [6,7] coauthored by E. S. Riseborough (the Scientific Authority) and R. M. Turner. Results from these studies have also been included in a paper [8] entitled: "Radar Tracking In Multipath: Techniques for Improved Performance" by R. M. Turner, E. Riseborough, and E. Bossé.

The scenarios that were studied combined the following aspects:

Azimuth and Elevation monopulse
Frequencies: 8.5, 9.25, 10.0, 10.75, 11.5 GHz
Targets Heights: 2.5, 5, 10, 20 meters
Angles off Boresight: 0, 5, 10, 15, 45 degrees
Side tilt: 25 degrees
Tilt Back: 20 degrees
With and Without Tapering
Sea-states: 2, 3
Constant SNR and 1/R**4 normalization
Noise Free and With Receiver Noise (several SNR values)

One method of reducing the phase monopulse angle estimation errors was to average the output errors for each frequency at each range to produce an average error at each range. This method suffered from giving equal weight to signals near zero amplitude. Therefore, to further reduce the angle estimation errors, a normalized error was calculated at each range by weighting each error with the squared amplitude of each signal. The RMS values for the errors were calculated and presented in table format for the above publications.

5.0 Radar Trials Support

Data was collected from experiments at Area 5 during the spring and fall of 1993 for testing main-beam and sidelobe cancellation techniques. Mr. D. Brookes was directly involved in most of these trials, either creating software to do in situ analysis of the data, to screen the data quality, troubleshoot computer systems problems, or to operate the systems and software during the experiments.

Several kinds of experiments were carried out during these trials. In the first set of trials on March 3, a relatively stable but unidentified target at a range of 14.4 km was used as the main target and a beacon jammer source was positioned at the 'white trailer' approximately 1.6 km from the receiver at an azimuth of between 10 and 15 degrees from boresight. The data was collected using two programs: SLC1 and SLC2. The first program would only sample a single specified range cell. SLC2, on the other hand would sample at numerous contiguous range cells before, beyond and on the target range cell. The step sizes (range cells) could be changed from one run to the next at the option of the operator. Several data files were collected using each of these programs under different receiver attenuation settings and with the beacon jammer alternately on, then off for comparison. In total, thirteen data files were collected on that day.

The next day, on March 4, trials were conducted with a corner reflector set up on the ice of the Ottawa River, approximately 6.7 km from the receiver, with a beacon jammer located in a side-lobe of the main-beam array approximately 1.0 km away. Eight data files were collected in a manner similar to the previous day. Later in the day a helicopter was used as the main target, to collect data for main-beam and side-lobe cancellation studies. A number of files were collected with the helicopter hovering at varying altitudes, at a distance of about 6.7 km with the beacon turned alternately on then off, and with the beacon jammer located in a sidelobe. In the second set of helicopter runs a similar format was followed, but with the jammer located in the main beam at a distance of 2.05 km. A total of 8 files were taken with the corner reflector and 38 files were accumulated for the helicopter runs.

On March 8, the last day of the spring trials, a corner reflector was positioned on the ice at about 2670 metres from the receiver and the jammer beacon was located at about at a distance of 1400 metres approximately 3 to 4 degrees off the centre of the main-beam. A total of 22 data files were recorded for this set of trials.

A more comprehensive account of these trials was documented by John Curnow of Applied Silicon Inc Canada and provided to the Scientific Authority. The analysis of this data is covered in Section 3.3.

In late August and early September of 1993 a new set of trials was conducted to collect data for main-beam and sidelobe cancelation techniques with a Rotman lens attached to the SLC array. The first set of trials was intended to determine the beam patterns of the (Rotman lens)-(SLC array) configuration. Special graphics software was written for the Matrox QG-640 colour graphics board and monitor attached to a micro-PDP11 host computer, a part of the Area 5 system. This was used for on site examination of the antenna patterns of the modified SLC array. The data for the antenna patterns was read from files consisting of 128 samples of In-phase and Quadrature signals for each antenna element of the array, at each of 81 angular positions (-20 to 20 degrees in 0.5 degree increments) of a stationary beacon relative to the array.

Two similar programs were created to plot the antenna patterns on the colour monitor. The program called ROTMAN was created to plot the signal amplitude for all 8 elements simultaneously, as a function of azimuthal angle. ROTMN1, however, was used for plotting out the antenna patterns of each individual antenna element. The above (Fortran IV) programs had to be linked to some previously developed graphics software (i.e. DRAWPT, and QGDRF4) in the following manner:

```
LINK ROTM**,DRAWPT.OBO,QGDRF4,SYLB4
```

and the programs made use of the graphics setup file called "ROTMNV.ANG". Similar programs, such as READROTMAN.FOR, were written in Fortran 77 for use on the MicroVAX at DREO for subsequent analysis of the data. A source listing for each of these routines is included in Appendix D. Figure 5.1 is a plot of the a test pattern used to verify that the ROTMN1 software was reading and sorting the data from the Slow Speed Sample and Hold (SSSH) network correctly. To run ROTMN1 the operator would enter the output channel of the Rotman lens and the software would plot the antenna pattern for that channel on the screen. In order to test the software, a predetermined set of DC signals were input to each channel of the SSSH. Each point on the graph corresponds to 128 samples of data taken at a particular azimuth angle, and each DC value was taken at 5 adjacent angle measurements. Therefore if the operator entered 1 as the Rotman lens output channel, then ROTMN1 should plot out the 5 values of the DC signal for I1, followed by 5 values for Q1, followed by 71 DC values near zero volts. When the results from all 16 I and Q channels are combined on the same plot, Figure 5.1 is the result.

Figures 5.2 to 5.10 are plots of the antenna patterns for each of the Rotman lens output channels, taken over a period of 3 days. Each plot combines the antenna patterns for each of the 8 channels as a function of azimuth angle, receiver attenuation, source frequency and beacon distance. The numbers above the antenna patterns, ranging from 1 to 8, left to right, indicate the approximate location of the main beam of the antenna pattern for the corresponding Rotman lens output channel. A few of the plots are incomplete because of systems problems that occurred before the run could be finished (eg. Figure 5.8). Some representative statistics of the plots shown in Figure 5.2
are shown in Table E1 in Appendix E. This table lists the minimum, maximum and average signal level for each output channel (horn), along with the standard deviation for each snapshot of 128 samples taken at each azimuth angle.

At the end of the contract the processing of the SLC data from the (Rotman lens)-(SLC array) configuration of the system was ongoing.

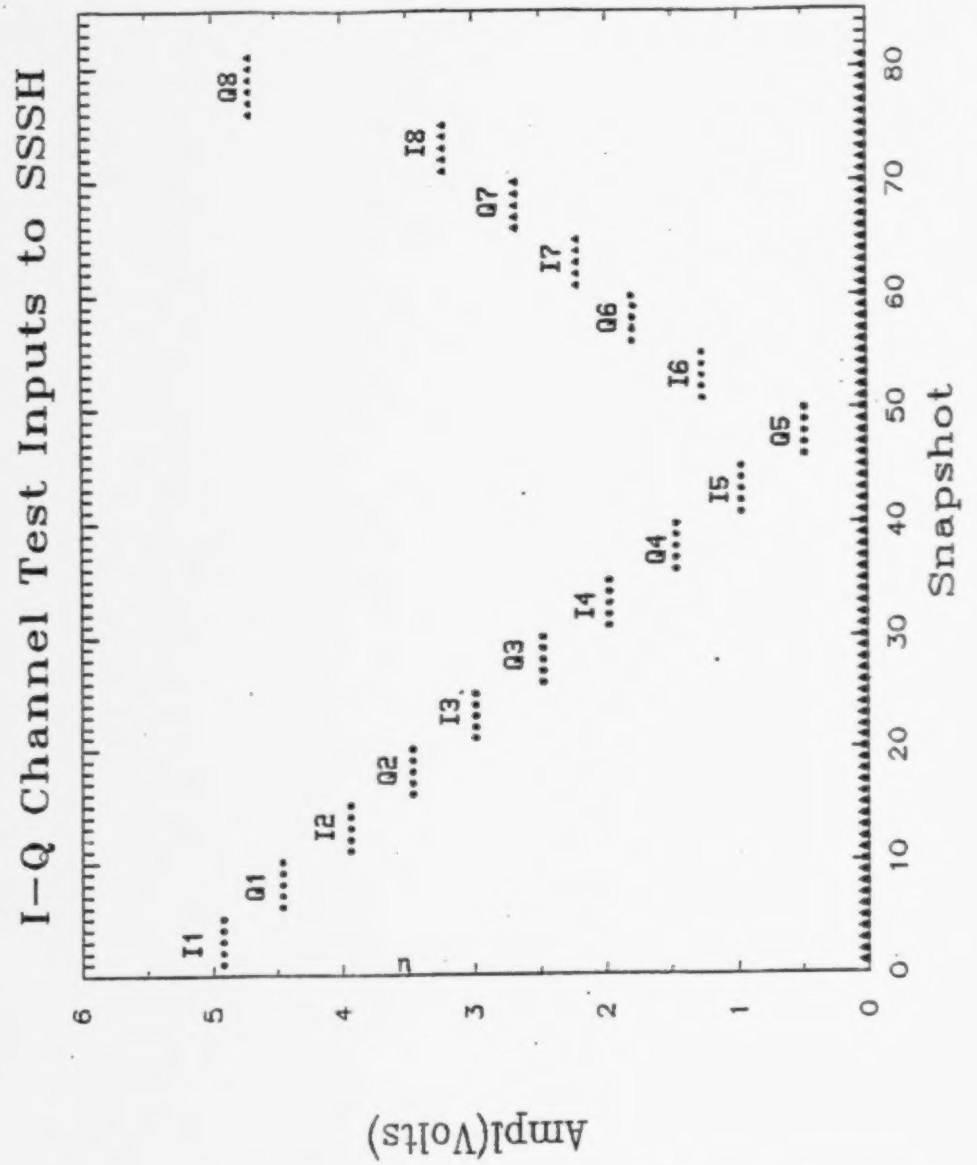


Figure 5.1 Test pattern plot to verify the correct operation of the ROTMN1 and READROTMAN software programs

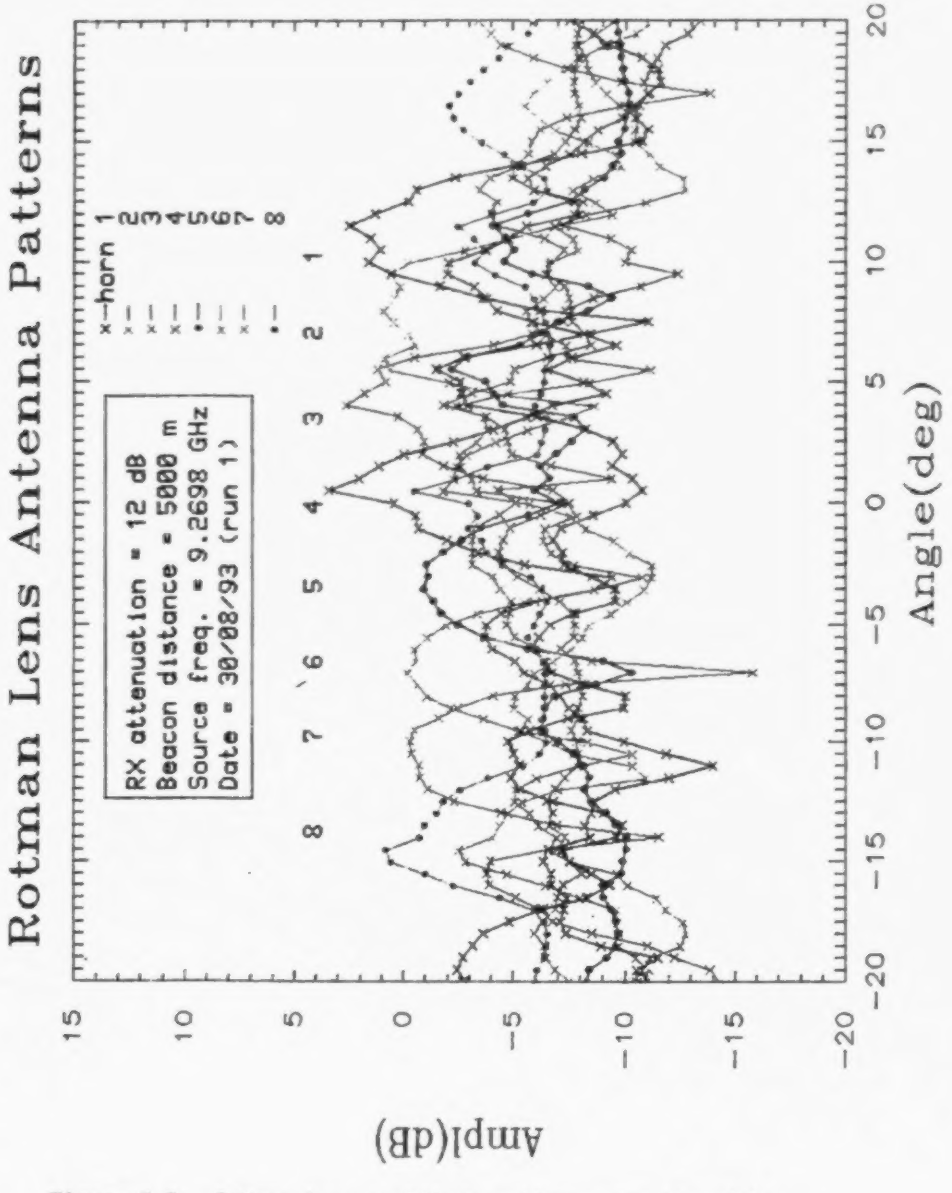


Figure 5.2 Rotman lens amplitude patterns for the eight output channels during Run1 on Aug. 30 1993

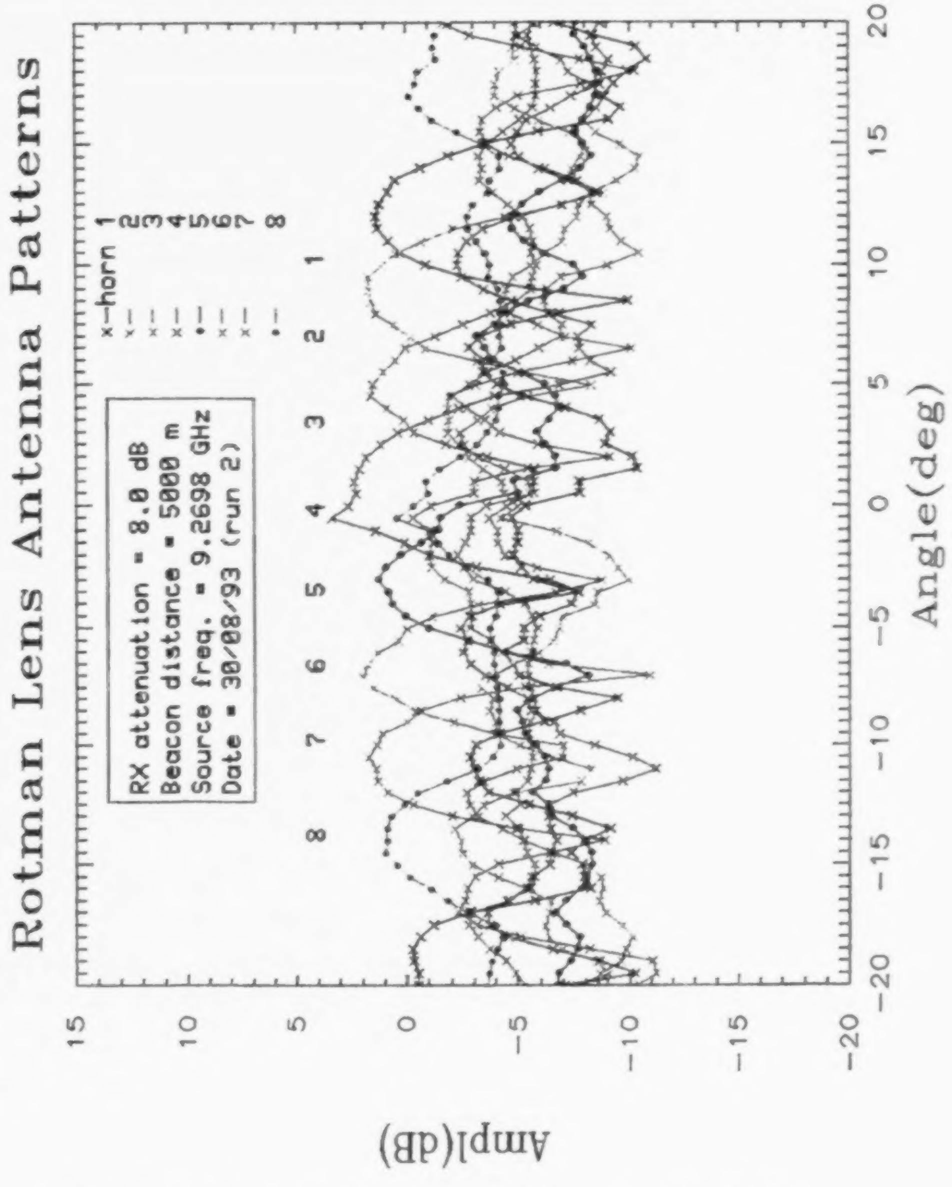


Figure 5.3 Rotman lens amplitude patterns for the eight output channels during Run 2 on Aug. 30 1993

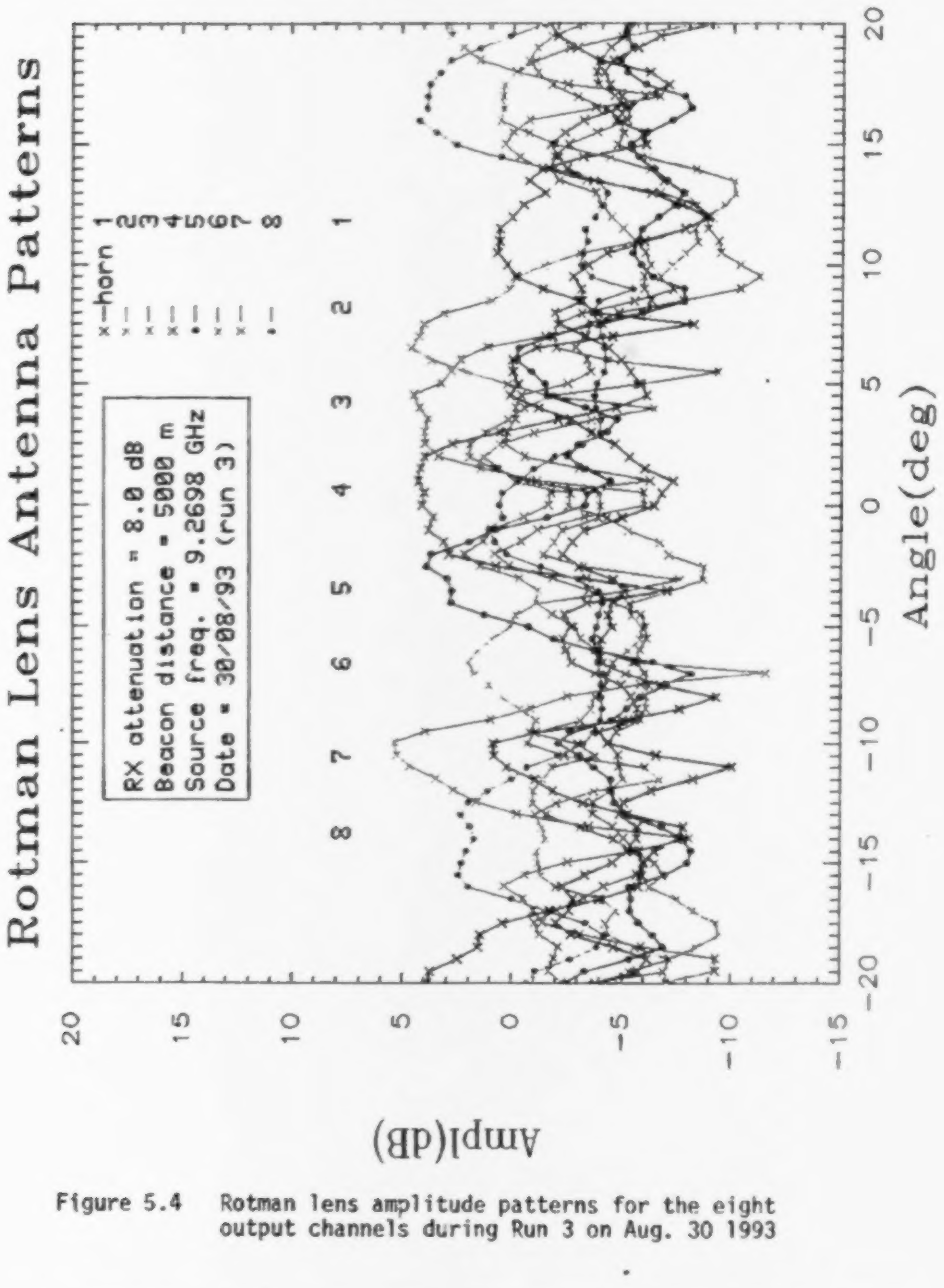


Figure 5.4 Rotman lens amplitude patterns for the eight output channels during Run 3 on Aug. 30 1993

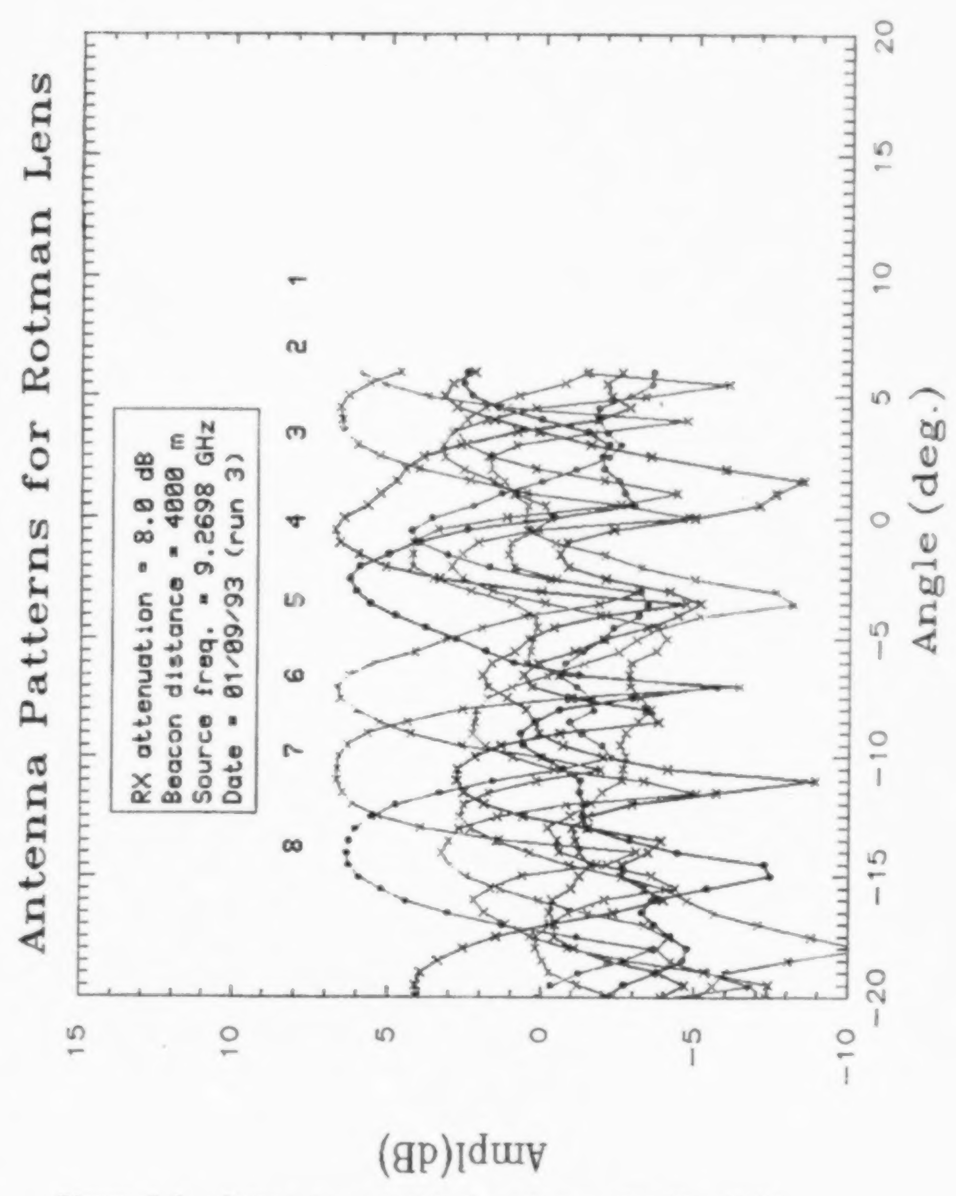


Figure 5.5 Rotman lens amplitude patterns for the eight output channels during Run 3 on Sept. 1 1993

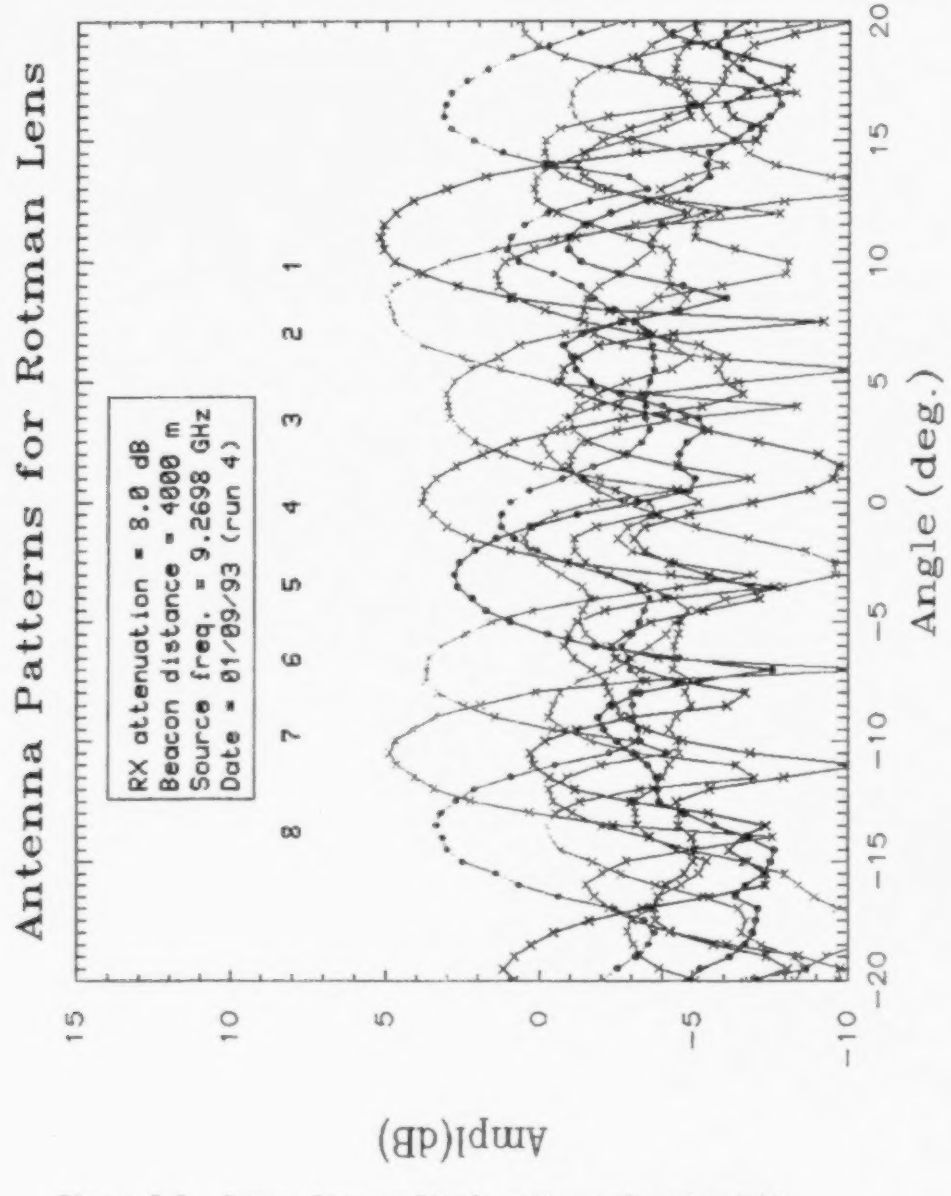


Figure 5.6 Rotman lens amplitude patterns for the eight output channels during Run 4 on Sept.1 1993

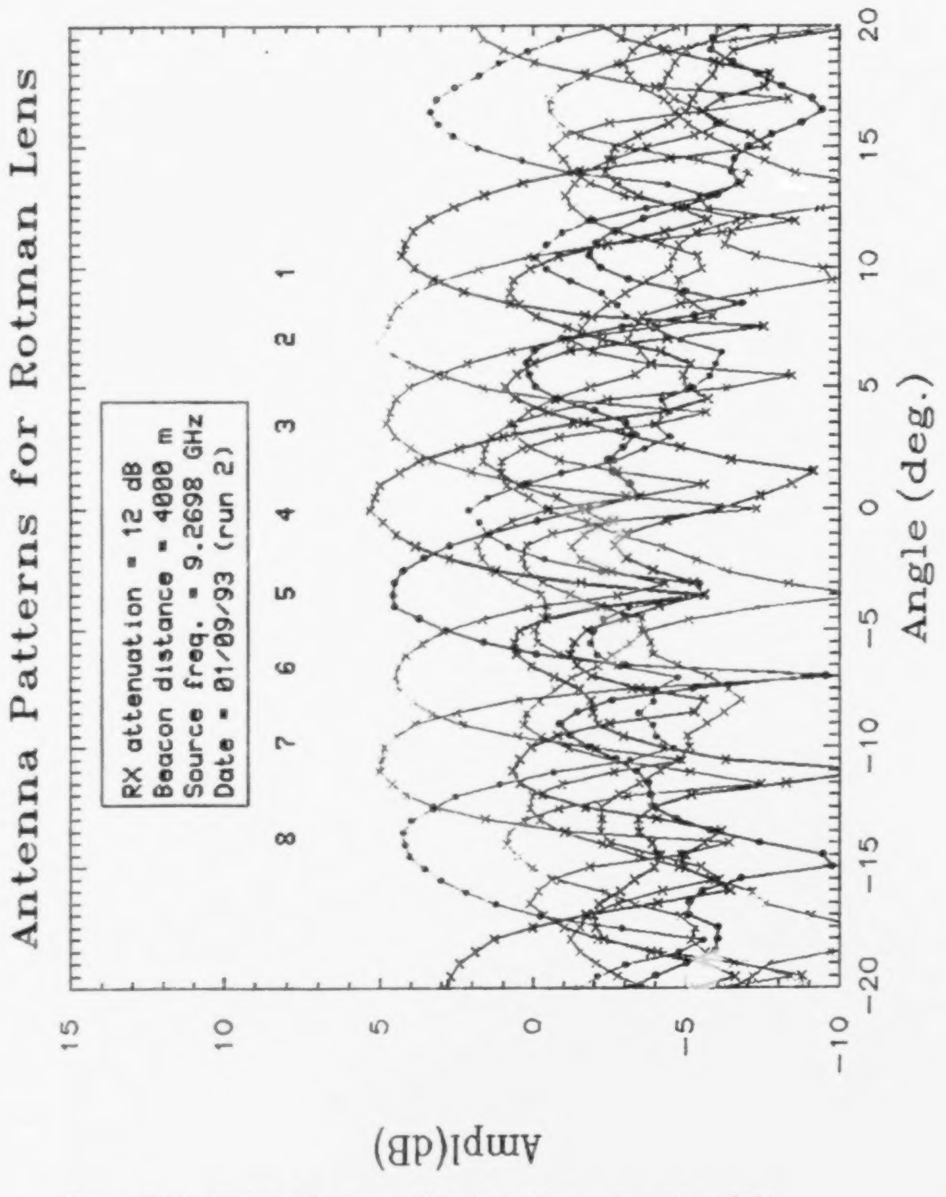


Figure 5.7 Rotman lens amplitude patterns for the eight output channels during Run 2 on Sept.1 1993

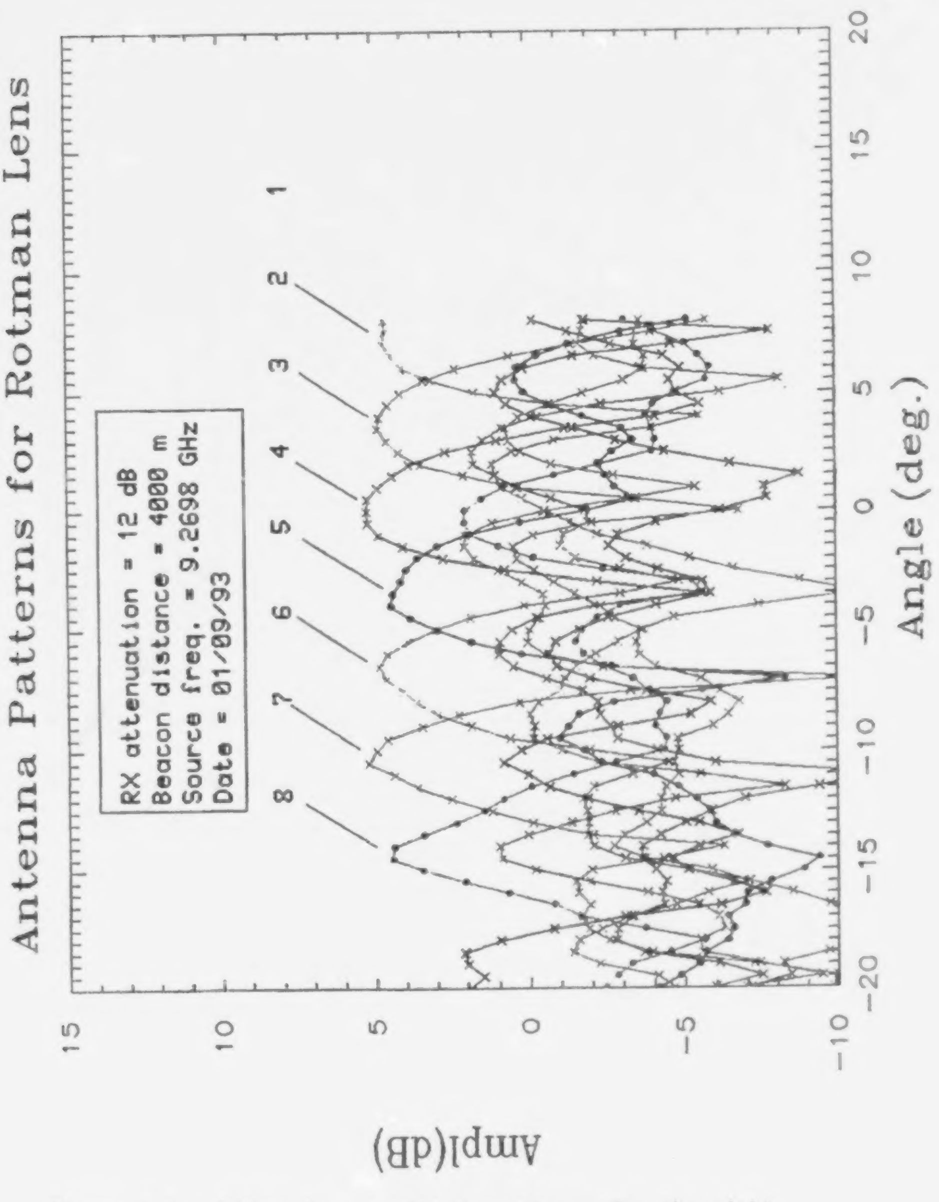


Figure 5.8 Rotman lens amplitude patterns for the eight output channels during Run 1 on Sept.1 1993

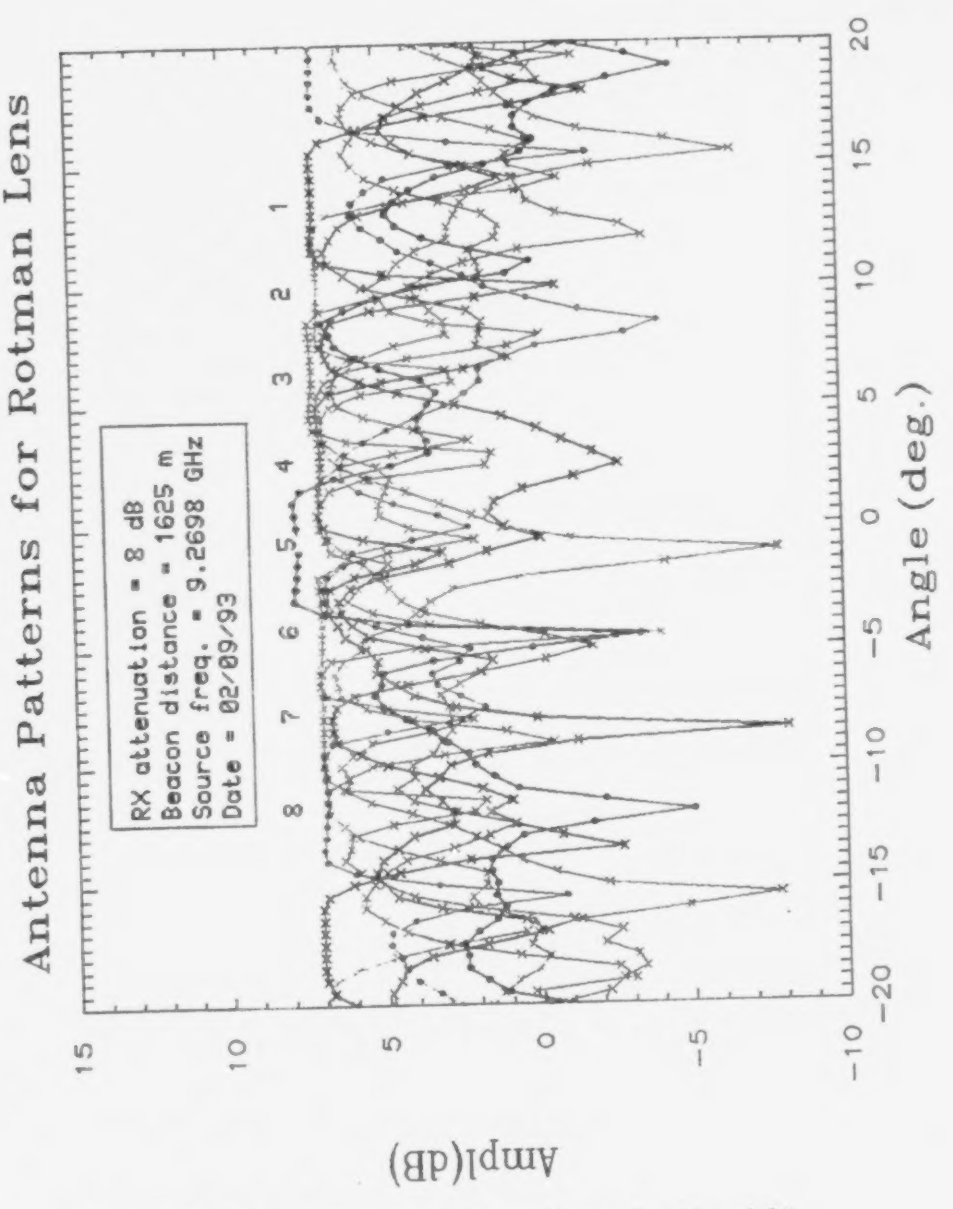


Figure 5.9 Rotman lens amplitude patterns for the eight output channels during Run 1 on Seot.2 1993

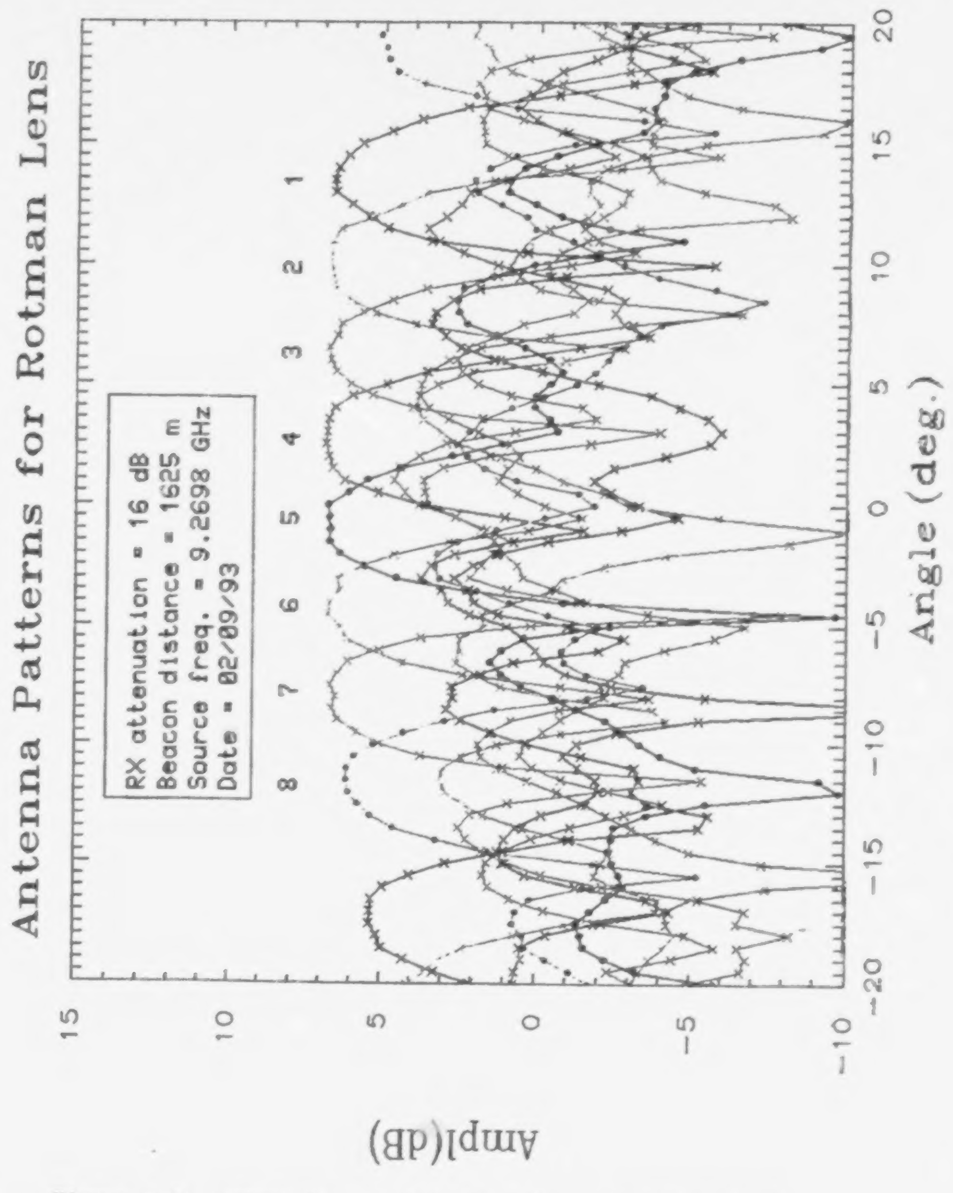


Figure 5.10 Rotman lens amplitude patterns for the eight output chennels during Run 2 on Sept.2 1993

APPENDIX A
STATEMENT OF WORK

WORK STATEMENT

The contractor is required to provide a system analyst and a programmer to carry out the following tasks:

1). Main-beam and Side-lobe Canceller Simulator Development

a) The contractor shall develop simulators for generating data inputs for main-beam and side-lobe cancellation programs. This will involve the setting up of a package to simulate a radar receiving target data in the main-beam and noise jammer data at various angles. Antenna gain patterns must be simulated for the main antenna and the side-lobe canceller antennas. The dispersive properties of the main receiver and the sidelobe receivers must be included in the simulation. Dispersion data for the experimental radar and its side-lobe canceller will be supplied for simulation studies. A noise jammer simulator will have to be developed as well. To correspond to a real-time environment, the simulator should model sampling of the target and surrounding range cells.

b) The contractor shall convert algorithms supplied by the Scientific Authority into computer simulators for the main-beam and side-lobe cancellation. After developing the simulators, the contractor shall perform sensitivity experiments on the algorithms.

c) The contractor shall convert experimental data to the form used by the main-beam and side-lobe cancellation simulators and analyze the effectiveness of the simulators. In June of 1990, sea trials were carried out on the experimental radar using Sea King helicopters. One acted as a target, and the second acted as a main-beam and a side-lobe jammer. There were 13 data files collected of size 2 MBytes during the trials. This data must be analysed to verify its usefulness in jammer cancellation. Data from the experimental radar system with its side-lobe canceller collected during the contract period must be analyzed as well.

d) The contractor shall add a multi-path simulation into the noise jammer sumulator and perform a study into the effect of propagation on jammer suppression.

System Analyst:	220 days
Senior Programmer:	104 days

2. Monopulse Sensitivity to Array Tilt Analysis

The contractor shall perform an analysis on the effect of array tilt due to ships motion on monopulse performance in the presence of multi-path.

System Programmer: 40 days

3. Radar Trial Support

The contractor shall support radar trials at Area 5 and possibly other locations by either direct participation in the trials or by upgrading software existing on the experimental radar system (see Annex 1) as required by the Scientific Authority.

System Analyst: 20 days

APPENDIX B
EARS PROJECT PERSONNEL

EARS Project Personnel

DREO Personnel

Ross Turner	Scientific Advisor
Ed Riseborough	Group Leader/Scientific Authority
Denis Lamothe	Technical Support S/H Unit, High Speed Data Aquisition

AIT Project Personnel

Stephen Sung	AIT Manager
Dan Brookes	Technical Leader/ Scientific Analyst
Anna Wilkinson	Senior Programmer

Applied Silicon Personnel

Ross Fines	Director/Contract manager
John Curnow	Contract Manager
Bob Moore	RF radar technician
Dany Longval	Digital Engineer
Manual Pablo-Dura	Digital technologist
Pierre Menard	Technician

APPENDIX C
TASK SHEETS

Table 1 Labour Breakdown by Task

Task	Systems Analyst(D.B.)	Senior Programmer(A.W.)
1 a)	45	30
b)	95	44
c)	80	30
2		40
3	20	
Total (days)	240	144

Table 2 Labour Breakdown by Month

Month ARO	Systems Analyst(D.B.)	Senior Programmer(A.W.)
1	20	12
2	20	12
3	15	9
4	20	12
5	20	12
6	20	12
7	20	12
8	20	12
9	20	12
10	20	12
11	10	6
12	20	12
13	15	9
Total (days)	240	144

APPENDIX D
SOURCE LISTINGS OF PROGRAMS AND SUBROUTINES

```
      PROGRAM  READROTMAN
C
C     AUTHOR   : DAN BROOKES
C     COMPANY  : AIT CORP.
C     DATE     : 1993
C
C     This program is for reading the data from the Rotman lens.
C     It produces 8 output files corresponding to each output
C     channel of the Rotman lens
C
    INTEGER*2 RD(128,8),ID(128,8),IDATA(255)
    INTEGER*2 TRNG,NRNG,START,COUNTER
    INTEGER*2 I1,I2,I3,I4,I5,I6,I7,I8
    INTEGER*2 Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8
    REAL SIG(128,8),ARG1,ARG2,ARG
      CHARACTER  FILENM*80,DATAFILE*40
      TYPE *,'INPUT FILENAME:'
      ACCEPT 10,FILENM
10    FORMAT(A40)
      OPEN(1,NAME=FILENM,FORM='UNFORMATTED',
      1 RECORDTYPE='VARIABLE',TYPE='OLD',
     1 READONLY,SHARED)
     k=1
     start=1
     mm=1
     klm=1
111   continue
      READ(1,END=13,ERR=13)idata
     nblock=nblock+1
112   continue
     if(klm.gt.2048.or.klm.eq.1)then
      k=1
      klm=1
      if(idata0.eq.0)then
        idata0=idata(mm+2)
      end if
      if(idata(mm+2).eq.idata0)type*,  idata0,' nblock ',nblock
      start=1
     end if
     if(klm.eq.1)then
```

```
          counter=idata(mm)
          nblock0=nblock
          type *,'counter ',counter
          trng=idata(mm+1)
          nrng=idata(mm+2)
          if(mm+3.ge.255)then
                mm=1
                  READ(1,END=13,ERR=13)idata
                nblock=nblock+1
                iqf=1
                k=1
                klm=1
                goto 888
          end if
          mm=mm+3
          iqf=1
        end if
         l=start
888       continue
           if(iqf.eq.1.and.(mod(mm,255).ne.0))then
             rd(k,l)=idata(mm)
             ni=ni+1
             mm=mm+1
             klm=klm+1
             l=l+1
             if(mod(l-1,8).eq.0)then
               iqf=2
               l=1
             end if
             goto 888
           else if(iqf.eq.1.and.(mod(mm,255).eq.0))then
             if(nblock.eq.nblock0)then
               mm=1
               start=l
               goto 111
             end if
             rd(k,l)=idata(mm)
             ni=ni+1
             mm=1
             klm=klm+1
             start=l+1
          if(mod(start-1,8).eq.0)then
            iqf=2
            start=1
          end if
          goto 111
        else if(iqf.eq.2.and.(mod(mm,255).ne.0))then
          id(k,l)=idata(mm)
          nq=nq+1
          mm=mm+1
          klm=klm+1
          l=l+1
          if(mod(l-1,8).eq.0)then
            iqf=1
            l=1
            i1=rd(k,8)
            i3=rd(k,7)
            i5=rd(k,6)
            i7=rd(k,5)
            q1=rd(k,4)
            q3=rd(k,3)
            q5=rd(k,2)
            q7=rd(k,1)
            i2=id(k,8)
            i4=id(k,7)
            i6=id(k,6)
            i8=id(k,5)
            q2=id(k,4)
            q4=id(k,3)
            q6=id(k,2)
            q8=id(k,1)
c
            rd(k,8)=i8
            rd(k,7)=i7
            rd(k,6)=i6
            rd(k,5)=i5
            rd(k,4)=i4
            rd(k,3)=i3
            rd(k,2)=i2
            rd(k,1)=i1
            id(k,8)=q8
            id(k,7)=q7
          id(k,6)=q6
          id(k,5)=q5
          id(k,4)=q4
          id(k,3)=q3
          id(k,2)=q2
          id(k,1)=q1
          k=k+1
          if(klm.eq.2049)goto 222
        end if
        goto 888
      else if(iqf.eq.2.and.(mod(mm,255).eq.0))then
        if(nblock.eq.nblock0.and.nblock0.gt.1)then
          mm=1
          start=l
          goto 111
        end if
        id(k,l)=idata(mm)
        nq=nq+1
        mm=1
        start=l+1
        klm=klm+1
        if(mod(start-1,8).eq.0)then
          iqf=1
          start=1
          i1=rd(k,8)
          i3=rd(k,7)
          i5=rd(k,6)
          i7=rd(k,5)
          q1=rd(k,4)
          q3=rd(k,3)
          q5=rd(k,2)
          q7=rd(k,1)
          i2=id(k,8)
          i4=id(k,7)
          i6=id(k,6)
          i8=id(k,5)
          q2=id(k,4)
          q4=id(k,3)
          q6=id(k,2)
          q8=id(k,1)
c
```

```
             rd(k,8)=i8
             rd(k,7)=i7
             rd(k,6)=i6
             rd(k,5)=i5
             rd(k,4)=i4
             rd(k,3)=i3
             rd(k,2)=i2
             rd(k,1)=i1
             id(k,8)=q8
             id(k,7)=q7
             id(k,6)=q6
             id(k,5)=q5
             id(k,4)=q4
             id(k,3)=q3
             id(k,2)=q2
             id(k,1)=q1
             k=k+1
             if(klm.eq.2049)goto 222
           end if
           goto 111
         end if
      if(klm.eq.2048)goto 222
222     continue
      count=count+1
      do l=1,8
      do k=1,128
        arg1=rd(k,l)
        arg2=id(k,l)
        arg=arg1**2+arg2**2
        sig(k,l)=sqrt(arg)*10./2048
        write(10+l,*)count,sig(k,l)
      end do
      end do
```

```
        if(mm.eq.256)then
          klm=1
           ni=0
           nq=0
          goto 111
        else if(mm.lt.256)then
          klm=1
           ni=0
           nq=0
          goto 112
        end if
13       continue
         END
```

```
      PROGRAM  ROTMN1
C
C     AUTHOR   : DAN BROOKES
C     COMPANY  : AIT CORP.
C     DATE     : 1993
C
C     This is a Fortran IV program for reading the Rotman lens
C     data files on a micro PDP-11. Using the graphics subroutine
C     Matft5, it plots the Rotman lens antenna pattern for a specified horn
C     on a Matrox colour monitor.
C
C
C
C
      REAL  THETA,DCNV,RDAT(8),IDAT(8)
      INTEGER  PLTYPE,INDAT(2051),KL,HORN
      KL=1
      DCNV=10./2048
      TYPE*,'Enter the horn number (1 to 8):'
      ACCEPT*,HORN
      THETA=-20.0
      PLTYPE=1
      CALL MATFT5(PLTYPE)
1     CONTINUE
      READ(4,END=5)INTDATA
2     CONTINUE
      DO 3 I=1,8
        RDAT(I)=INTDAT((KL-1)*16+I+3)
        IDAT(I)=INTDAT((2*KL-1)*8+I+3)
3     CONTINUE
              I1=RDAT(8)
              I3=RDAT(7)
              I5=RDAT(6)
              I7=RDAT(5)
              Q1=RDAT(4)
              Q3=RDAT(3)
              Q5=RDAT(2)
              Q7=RDAT(1)
              I2=IDAT(8)
              I4=IDAT(7)
              I6=IDAT(6)
```

```
          I8=IDAT(5)
          Q2=IDAT(4)
          Q4=IDAT(3)
          Q6=IDAT(2)
          Q8=IDAT(1)
          RDAT(1)=I1
          RDAT(2)=I2
          RDAT(3)=I3
          RDAT(4)=I4
          RDAT(5)=I5
          RDAT(6)=I6
          RDAT(7)=I7
          RDAT(8)=I8
          IDAT(1)=Q1
          IDAT(2)=Q2
          IDAT(3)=Q3
          IDAT(4)=Q4
          IDAT(5)=Q5
          IDAT(6)=Q6
          IDAT(7)=Q7
          RDAT(8)=Q8
      DO 30, I=1,8
          Z(I)=SQRT(RDAT(I)**2+IDAT(I)**2)*DCNV
30    CONTINUE
      KL=KL+1
      CALL DRAWPT(THETA,Z(HORN))
      IF(KL.LE.128)GOTO 4
          KL=1
          THETA=THETA+0.5
          GOTO 1
4     CONTINUE
      GOTO 2
5     CONTINUE
      END
      SUBROUTINE  MATFT5(PLOT)
C
C
C     FILE: MATSUB.FOR
C
C     AUTHOR:  ED RISEBOROUGH  JAN. 88
C                   (MODIFIED  BY DAN BROOKES  AUG. 93)
C
C     THIS SUBROUTINE  IS TO SET UP THE AXES FOR PLOTTING
C     USING QG640 GRAPHICS  ON A MATROX  MONITOR. USES A
C     PLOT  FILE  TO  SET  UP  THE  AXES  AS  YOU  DESIRE  (AN
C     EXAMPLE  IS IN EDPLOT.RUN).  USES SUBROUTINE  QGPORT
C     TO PASS DATA TO  THE GRAPHICS  MONITOR.
C
      BYTE  PCON(100),ZERTO1,LABELX(20),LABELY(20)
      BYTE  FILENM(11),TITLE(20),ZERO2
      DATA  FILENM/' ','','','','','','','','','',0/
      INTEGER  PLOT
C
10    FORMAT('  MOVE  ',F8.2,",F8.2,'$')
11    FORMAT('  DRAW  ',F8.2,",F8.2,'$')
12    FORMAT('  TSIZE  ',F8.2,'$')
13    FORMAT('  TEXT  ',20A1,'$')
14    FORMAT(100A1)
15    FORMAT('  TEXT  ',I8,'$')
16    FORMAT('  VWPORT  ',I8,3(1X,I8),'$')
17    FORMAT('  WINDOW  ',F8.2,3(1X,F9.2);$')
18    FORMAT(1X,100A1)
19    FORMAT('  CLEARS  ',I3,'$')
20    FORMAT('  COLOR  ',I3,'$')
101   FORMAT(/)
C
C     OPEN  PLOT PROFILE  FILE
C
D     TYPE*,'INPUT FILENAME'
D     ACCEPT(14,FILENM(I),I=1,10
      IF(PLOT.EQ.4)GOTO  888
      IF(PLOT.EQ.3)GOTO  889
      IF(PLOT.EQ.2)GOTO  890
      OPEN(UNIT=76,NAME='ROTMNV.ANG',
     *TYPE='OLD',READONLY)
```

```
      GOTO 891
890   OPEN(UNIT=76,NAME='DBPLT.WTR',
     *TYPE='OLD',READONLY)
      GOTO 891
889   OPEN(UNIT=76,NAME='DBPLT.RUN',
     *TYPE='OLD',READONLY)
      GOTO 891
888   OPEN(UNIT=76,NAME='DHGHT.RUN',
     *TYPE='OLD',READONLY)
891   CONTINUE
C
C     QG INITIALIZATION
C
      CALL QGPORT(12,'RESETF  CLS 0 $')
      CALL QGPORT(8,'TSTYLE  1 $')
      CALL DELAY
C
C     INPUT BACKGROUND  COLOUR
C
      READ(76,*)
      READ(76,*)I
      ENCODE(12,19,PCOM)I
      CALL QGPORT(12,PCOM)
      CALL  DELAY
C     PAUSE
C
C     INPUT AXIS COLOUR
C
      READ(76,*)
      READ(76,*)I
      ENCODE(11,20,PCOM)I
      CALL  QGPORT(11,PCOM)
      CALL DELAY
C     PAUSE
C
C     SET LABEL TEXT SIZE
C
      TSIZE =10.
      ENCODE(15,12,PCOM)TSIZE
      CALL QGPORT(15,PCOM)
      CALL DELAY
```

```
C     PAUSE
C
C     LABEL X
C
C     SET UP X LABEL ROTATION
C
C
      CALL QGPORT(9,'TANGLE  0 $')
      CALL QGPORT(9,'TCHROT  0 $')
C
C     INPUT X POSITION OF LABEL
C
      READ(76,*)
      READ(76,*)X
      Y=-190.
      ENCODE(27,10,PCOM)X,Y
      CALL QGPORT(27,PCOM)
      CALL DELAY
C     PAUSE
C
C     INPUT X LABEL LENGTH
C
      READ(76,*)
      READ(76,*)(LABELX(I),I=1,LEN)
      ENCODE(27,13,PCOM)LABELX
      QGPORT(27,PCOM)
      CALL DELAY
C     PAUSE
C
C     LABEL Y
C
C     INPUT Y POSITION OF Y LABEL
C
C
      READ(76,*)
      READ(76,*)Y
      X=-280.
      ENCODE(27,10,PCOM)X,Y
      QGPORT(27,PCOM)
      CALL DELAY
C     PAUSE
```

```
C
C     SET UP Y LABEL ROTATION
C
      CALL QGPORT(10,'TANGLE  90 $')
      CALL DELAY
      CALL QGPORT(10,'TCHROT  90 $')
      CALL DELAY
C
C     INPUT Y LABEL LENGTH
C
      READ(76,*)
      READ(76,*)(LABELY(I),I=1,LEN)
      ENCODE(27,13,PCOM)LABELY
      QGPORT(27,PCOM)
      CALL DELAY
C     PAUSE
C
C     TITLE
C
C     INPUT X POSITION OF TITLE
C
C
      READ(76,*)
      READ(76,*)X
      Y=185.
      ENCODE(27,10,PCOM)X,Y
      QGPORT(27,PCOM)
      CALL DELAY
C
C     SET UP TITLE LABEL  ROTATION
C
      CALL QGPORT(9,'TANGLE  0 $')
      CALL DELAY
      CALL QGPORT(9,'TCHROT  0 $')
      CALL DELAY
C
C     INPUT TITLE
C
      READ(76,*)
      READ((TITLE(I),I=1,LEN)
      ENCODE(27,13,PCOM)TITLE
      QGPORT(27,PCOM)
      CALL DELAY
C
C     SET UP AXES
C
C     INITIALIZE SCREEN LIMITS
C
      CALL QGPORT(27,'WINDOW  0.0 639.0 0.0 479.0 $')
C
C     SET WINDOW ON SCREEN
C
      XMIN=100.
      XMAX=550.
      YMIN=90.
      YMAX=420.
C
C     INPUT VIRTUAL AXIS LIMITS
C
      READ(76,*)
      READ(76,*)XMINV,XMAXV,YMINV,YMAXV
      IXMIN=XMIN
      IXMAX=XMAX
      IYMIN=YMIN
      IYMAX=YMAX
      ENCODE(27,10,PCOM)XMIN,YMAX
      QGPORT(27,PCOM)
      CALL DELAY
      ENCODE(27,10,PCOM)XMIN,YMIN
      CALL QGPORT(27,PCOM)
      CALL DELAY
      ENCODE(27,10,PCOM)XMAX,YMIN
      CALL QGPORT(27,PCOM)
      CALL DELAY
C     PAUSE
```

```
C
C     XTICKS
C
C     INPUT NUMBER  OF XTICKS
C
      READ(76,*)
2     READ(76,*)XNTICK
      XINC=(XMAX-XMIN)/(XNTICK-1.)
      XTSIZE=10.
      VAL=XMIN
      NTICK=XNTICK
      DO 1 I=1,NTICK-1
            VAL=VAL+XINC
            ENCODE(27,10,PCOM)VAL,YMIN
            CALL QGPORT(27,PCOM)
            ENCODE(27,11,PCOM)VAL,YMIN+XTSIZE
            CALL QGPORT(27,PCOM)
1     CONTINUE
      CALL DELAY
C     PAUSE
C
C     YTICKS
C
C     INPUT NUMBER  OF YTICKS
C

      READ(76,*)
      READ(76,*)YNTICK
      YINC=(YMAX-YMIN)/(YNTICK-1.)
      YTSIZE=10.
      VAL=YMIN
      NTICK=YNTICK
      DO 2 I=1,NTICK-1
            VAL=VAL+YINC
            ENCODE(27,10,PCOM)XMIN,VAL
            CALL QGPORT(27,PCOM)
            ENCODE(27,11,PCOM)XMIN+YTSIZE,VAL
            CALL QGPORT(27,PCOM)
2     CONTINUE
      CALL DELAY
C     PAUSE
```

```
C
C     GRID  OF BIG  TICK
C
C     SET UP ROTATION  FOR MARK  OR GRID  LABELS
C
      CALL  QGPORT(9,'TANGLE   0 $')
      CALL  QGPORT(9,'TCHROT   0 $')
C
C     CINPUT  1 FOR  GRID,  2 FOR  BIG  TICK
C
      READ(76,*)
      READ(76,*)IGFLAG
C
C     XGRID
C
C     INPUT  NUMBER  OF X MARKS
C
      READ(76,*)
      READ(76,*)XNTICK
      XINC=(XMAX-XMIN)/(XNTICK-1.)
      VAL=XMIN
      XINCV=(XMAXV-XMINV)/(XNTICK-1.)
      VALV=XMINV
      XTSIZE=XTSIZE*2.0
      IF(IGFLAG.EQ.1)XTSIZE=YMAX-YMIN
      NTICK=XNTICK
      DO 3 I=0,NTICK-1
            ENCODE(27,10,PCOM)VAL,YMIN
            CALL  QGPORT(27,PCOM)
            ENCODE(27,11,PCOM)VAL,YMIN+XTSIZE
            CALL  QGPORT(27,PCOM)
            IVAL=VALV
            XNCH=1
            IF(IVAL.GE.10)XNCH=2.
            IF(IVAL.GE.100)XNCH=3.
            IF(IVAL.GE.1000)XNCH=4.
            IF(IVAL.GE.10000)XNCH=5.
            XPOS=VAL-(XNCH*TSIZE)/2.
            ENCODE(27,10,PCOM)XPOS,YMIN-15
            QGPORT(27,PCOM)
            ENCODE(15,15,PCOM)IVAL
```

```
             CALL QGPORT(15,PCOM)
             VAL=VAL+XINC
             VALV=VALV+XINCV
3        CONTINUE
         CALL DELAY
C        PAUSE
C
C        Y GRID
C
C        INPUT NUMBER  OF Y MARKS
C
         READ(76,*)
         READ(76,*)YNTICK
         YINC=(YMAX-YMIN)/(YNTICK-1.)
         VAL=YMIN
         YINCV=(YMAXV-YMINV)/YNTICK-1.)
         VALV=YMINV
         YTSIZE=YTSIZE*2.0
         IF(IFLAG.EQ.1)YTSIZE=XMAX-XMIN
         NTICK=YNTICK
         DO 4 I=0,NTICK-1
             ENCODE(27,10,PCOM)XMIN,VAL
             CALL QGPORT(27,PCOM)
             ENCODE(27,11,PCOM)XMIN+YTSIZE,VAL
             CALL QGPORT(27,PCOM)
             IVAL=VALV
             XNCH=1
             IF(IVAL.GE.10)XNCH=2.
             IF(IVAL.GE.100)XNCH=3.
             IF(IVAL.GE.1000)XNCH=4.
             IF(IVAL.GE.10000)XNCH=5.
             XPOS=XMIN-(XNCH*TSIZE)-1.
             ENCODE(27,10,PCOM)XPOS,VAL
             QGPORT(27,PCOM)
             ENCODE(15,15,PCOM)IVAL
             CALL QGPORT(15,PCOM)
             VAL=VAL+YINC
             VALV=VALV+YINCV
4        CONTINUE
         CALL DELAY
C        PAUSE
```

```
C
C     SET UP FOR PLOTTING
C
      ENCODE(44,16,PCOM)IXMIN,IXMAX,IYMIN,IYMAX
      CALL QGPORT(44,PCOM)
      ENCODE(44,17,PCOM)XMINV,XMAXV,YMINV,YMAXV
      CALL QGPORT(44,PCOM)
C
C     INPUT LINE COLOUR
C
      READ(76,*)
      READ(76,*)I
      ENCODE(11,20,PCOM)I
      CALL QGPORT(11,PCOM)
      CLOSE(UNIT=76)
      RETURN
      END
      SUBROUTINE  DELAY
      DO 2 I=1,100
      DO 1 J=1,100
         K=I+J
1     CONTINUE
2     CONTINUE
      RETURN
      END
      Program MYSLC
C
C      AUTHOR    : DAN BROOKES
C      COMPANY   : AIT CORP
C      DATE      : 1993
C
C
C      This program uses a simple sidelobe cancellation
C      algorithm
C
C
C
      real      xin,z,x(16),y(16),rxfft(4096)
      real      pr(8),minv,v(5000),fmr(2),pt
      complex   fm,ymb(8),yslc(8),xfft(2048)
      complex   res(8),ccorr(8),ccorr0(8),wo(8)
      integer   ind,length,istat,nav,npav
      character infile1*40,infile2*40,outfile*40
      type*,'Enter the name of the main beam data file:'
      accept11,infile1
11    format(a80)
      type*,'Enter the name of the slc beam data file:'
      accept11,infile2
      type *,'Enter the estimation sample number'
      accept*,length
      open(unit=1,file=infile1,type='old',form='unformatted',
     *     readonly,shared)
      open(unit=2,file=infile2,type='old',form='unformatted',
     *     readonly,shared)
      open(unit=3,file='totpow.dat',type='new')
      call apinit(0,0,istat)
      nav=1
      npav=1
1     continue
      read(1,err=333)(x(j),j=1,16)
      read(2,err=333)(y(j),j=1,16)
      do j=1,8
        ymb(j)=cmplx(x(2*j-1),x(2*j))
        yslc(j)=cmplx(y(2*j-1),y(2*j))
      end do
      do j=1,4096
       if(j.le.16)then
         rxfft(j)=y(j)
       else if(j.gt.16)then
         rxfft(j)=0.0
       end if
      end do
      call apput(rxfft,1000,4096,2)
      call apwd
      call cfft(1000,2048,1)
      call apwr
      call cfftsc(1000,2048)
      call apwr
      call cvmags(1000,2,11000,1,2048)
      call apwr
      call xmaxv(11000,1,1,2048)
      call apwr
      call apget(z,1,1,2)
      call apwd
      call apget(xin,2,1,2)
      call apwr
      ind=1000+2*xin-1
      call apget(fmr,ind,2,2)
      call apwd
      fm=cmplx(fmr(1),fmr(2))
      minv=((nav-1)*minv+z)/nav
      do j=1,8
        if(npav.le.length)then
          ccorr(j)=(ccorr0(j)+(nav-1)*ccorr(j)
     *    +ymb(j)*conjg(fm))/nav
          wo(j)=ccorr(j)/minv
        end if
        res(j)=(ymb(j)-wo(j)*fm)
        ccorr0(j)=cmplx(0.0,0.0)
      end do
      if(npav.lt.length)then
      if(nav.eq.length)then
        do j=1,8
          ccorr0(j)=ccorr(j)
          ccorr(j)=cmplx(0.0,0.0)
        end do
```

```
          nav=1
        end if
        end if
c
c   now calculate the instantaneous  residue power
c
        pt=0.0
        do j=1,8
          pr(j)=res(j)*conjg(res(j))
          pt=pt+pr(j)
          pr(j)=10*log10(pr(j)+1e-12)
        end do
        pt=10*log10(pt+1e-12)
        write(3,4)npav,pt,(pr(j),j=1,8)
4       format(1x,i5,9f7.2)
        nav=nav+1
        npav=npav+1
        IF(MOD(NPAV,100).EQ.0)type  *,'sample no=',npav
        go to 1
333     continue
        end
```

```
      PROGRAM  SIMSLCMP
c
c
c   Author  : Dan Brookes
c   Company: AIT Corp.
c   Date    : 1993
c
c
c   This program is for simulating data from an 8 element main beam
c   array and a similar array for a side lobe canceller. the data
c   can be used to test the side lobe cancellation software called
c   myslcpc.for
c
c
c
c
c
       REAL        XNOIS,YNOIS,STD1,STD2,SLC(16),MB(16),swh,freq
       REAL*8      PI,WAVN,RT2(8),RJ2(8),C,FR,WVL,PHIT,WT,T
       REAL*8      PHIJ,THETAJ,A,B,D,RJ,RT,PJ,PT,SLCGAIN,MBGAIN
       REAL*8      WMB,WSLC,DT,TRANG,JRANG,hrx1,theta,COS1,SIN1
       REAL*8      RJ1(8),RJ3(8),RT1(8),RT3(8),PSIT(8),PSIJ(8)
       REAL*8      DIELRL,DIELIM,HRX,HJAM,HTARG,DELTA(8)
       COMPLEX*16  MSIGT(8),MSIGJ(8),SSIGJ(8),SSIGT(8)
       COMPLEX*16  BETA(8),ETA(8),ES(8),EM(8),sigi,sigd
       COMPLEX*16  SRHOJ(8),SRHOT(8),DIELSR
       COMPLEX     N1(8),N2(8)
c
c
c
       TYPE*,'Enter the main beam gain and slc gain:'
       ACCEPT*,MBGAIN,SLCGAIN
       TYPE *,'Enter the target amplitude and jammer amplitude:'
       ACCEPT*,PT,PJ
       TYPE*,'Enter the main beam and slc array width (m):'
       ACCEPT*,WMB,WSLC
       TYPE *,'Enter the jammer angle from boresight (deg):'
       ACCEPT*,THETAJ
       TYPE *,'Enter the noise std for mb and slc receivers:'
       ACCEPT*,STD2,STD1
```

```
        TYPE *,'Enter the height of the jammer, the target and
      * receiver resp.:'
        ACCEPT*,HJAM,HTARG,HRX
        TYPE *,'INCLUDE MULTIPATH  OR NO MULTIPATH  (1,OR 0
     1 RESP.):'
        ACCEPT*,MP
        IF(MP.EQ.1)THEN
          TYPE *,'Enter the real and imaginary part of the
     * dielectric const.:'
          ACCEPT*,DIELRL,DIELIM
        END IF
        DIELSR=CDSQRT(DCMPLX(DIELRL,DIELIM))
        DIELRL=DREAL(DIELSR)*2D0
        DIELIM=DIMAG(DIELSR)*2D0
c
c     for this program we will assume flat earth geometry and
c     that the slc array is oriented horizontally.
c
c
c
        A=WMB/7D0
        B=WSLC/7D0
        D=.5D0
        DT=2.0D-3
        PI=4.0D0*DATAN(1.0D0)
        FR=9.6D9
        FREQ=9.6
        C=2.998D8
        RJ=7900D0
        RT=16000D0
        WVL=C/FR
        JRANG=(HRX+HJAM)/RJ
        TRANG=(HRX+HTARG)/RT
        CONFG=1
C
C      THE FOLLOWING  DO LOOP IS TO DO INITIAL
C      CALCULATIONS  OF THE SIGNAL RECEIVED  AT THE
C      SIDE-LOBE  CANCELLER  ARRAY
C
C
C
```

```
C
      DO I=1,8
C
C       THE SIGNAL FROM THE TARGET IS GIVEN BY THE
C       FOLLOWING
C
C
      THETA=0.D0
      CALL BEAMPAT2(HRX,HTARG,RT,SIGD,SIGI,FREQ,THETA,
     1      I,SWH)
      IF(MP.EQ.1)THEN
        ssigt(i)=(SIGD+SIGI)*PT
      ELSE IF(MP.EQ.0)THEN
        SSIGT(I)=SIGD*PT
      END IF
C
C      THE SIGNAL FROM THE JAMMER IS GIVEN BY THE
C      FOLLOWING
C
      CALL BEAMPAT2(HRX,HJAM,RJ,SIGD,SIGI,FREQ,THETAJ,
     1      I,SWH)
      IF(MP.EQ.1)THEN
        SSIGJ(i)=(SIGD+SIGI)*PJ
      ELSE IF(MP.EQ.0)THEN
        SSIGJ(I)=SIGD*PJ
      END IF
      END DO
c
c     note: above combined signals do not take into account the
c           power of the jammer or target signals (this will be
c           included later by
c           multiplication of the appropriate factors.)
c
c
c     the following do loop is to do the initial calcutions for
c     the received signals at the main beam array.(again assume
c     that the receiver array is broadside to the target, but is
c     also oriented at right angles to the slc array and the
c     reflecting surface
c
c
```

```
      do i=1,8
C
C      FIRST CALCULATE  SIGNAL DUE TO TARGET
C
C
       THETA=0.D0
       HRX1=(HRX+D+(I-1)*A)
       CALL  BEAMPAT1(HRX1,HTARG,RT,FREQ,SIGD,
     *   SIGI,THETA,SWH)
       IF(MP.EQ.0)THEN
        MSIGT(I)=SIGD*PT
       ELSE IF(MP.EQ.1)THEN
        MSIGT(I)=(SIGD+SIGI)*PT
       END IF
C
C      NOW CALCULATE  SIGNAL DUE TO JAMMER
C
C
       CALL BEAMPAT1(HRX1,HJAM,RJ,FREQ,SIGD,
     *   SIGI,THETAJ,SWH)
       IF(MP.EQ.0)THEN
        MSIGJ(I)=SIGD*PJ
       ELSE IF(MP.EQ.1)THEN
        MSIGJ(I)=(SIGD+SIGI)*PJ
       END IF
c
      END DO
c
c
      OPEN(UNIT=71,FILE='HTRAW.DAT',TYPE='NEW',
     1     FORM='UNFORMATTED')
      OPEN(UNIT=72,FILE='HTSLC.DAT',TYPE='NEW',
     1     FORM='UNFORMATTED')
       DO J=90,110
        DO JJ=1,256
         T=T+DT
         WT=2.D0*PI*FR*T
        DO I=1,8
         BETA(I)=SLCGAIN*DCMPLX(1.0D0,0.0D0)
         ETA(I)=MBGAIN*DCMPLX(1.0D0,0.0D0)
c
```

```
c
        CALL GNOIS(XNOIS,0,STD1,0)
        CALL GNOIS(YNOIS,0,STD1,0)
        N1(I)=CMPLX(XNOIS,YNOIS)
        CALL GNOIS(XNOIS,0,STD2,0)
        CALL GNOIS(YNOIS,0,STD2,0)
        N2(I)=CMPLX(XNOIS,YNOIS)
        PHIT=0.D0
        PHIJ=0.D0
        BETA(I)=BETA(I)*DCMPLX(DCOS(WT+PHIJ),
   1     DSIN(WT+PHIJ))
       ETA(I)=ETA(I)*DC  MPLX(DCOS(WT+PHIT),DSIN(WT+PHIT))
      IF(J.NE.100)THEN
       ES(I)=BETA(I)*SSIGJ(I)+N1(I)
       EM(I)=ETA(I)*MSIGJ(I)+N2(I)
      ELSE IF(J.EQ.100)THEN
        ES(I)=BETA(I)*(SSIGJ(I)+SSIGT(I))+N1(I)
        EM(I)=ETA(I)*MSIGJ(I)
       EM(I)=EM(I)+ETA(I)*MSIGT(I)+N2(I)  !JAM.+TARG.+NOISE
      END IF
      SLC(2*I-1)=REAL(ES(I))
      SLC(2*I)=DIMAG(ES(I))
      MB(2*I-1)=REAL(EM(I))
      MB(2*I)=DIMAG(EM(I))
     END DO
          WRITE(71)(MB(I),I=1,16)
          IF(JJ.LT.2)THEN
           WRITE(73,*)(MB(I),I=1,16)
           WRITE(74,*)(SLC(I),I=1,16)
          END IF
          WRITE(72)(SLC(I),I=1,16)
     END DO
    END DO
    END
```

```
      SUBROUTINE   GNOIS(XNOIS,AVE,STD,ITYPE)
C
C GENERATE  A NOISE SAMPLE FROM UNIFORM  OR GAUSSIAN
C DISTRIBUTION
C
C FUNCTION  REQUIRED:   RAN
C
C INPUT:
C   AVE  = MEAN  OF NOISE  DISTRIBUTION
C   ITYPE  = TYPE  OF NOISE  DISTRIBUTION
C          = 1, UNIFORM
C          = OTHERWISE,  GAUSSIAN
C   STD  = NOISE  STANDARD  DEVIATION
C
C OUTPUT:
C   XNOIS  = NOISE  OUTPUT
C
      DATA  J,ROOT12/4000,3.4641016/
C
      IF(ITYPE.NE.1)  GOTO  10
        XF = RAN(J)
        XNOIS  = STD*ROOT12*(XF-0.5)+AVE
      RETURN
C
   10 SUM  = 0.0
      DO  20 I=1,12
        XF = RAN(J)
        SUM  = SUM+XF
   20 CONTINUE
      XNOIS  = STD*(SUM-6.0)+AVE
      RETURN
      END
      SUBROUTINE   BEAMPAT1(HRX,HTARG,Z,FREQ,SIGD,
     * SIGI,THETA,SWH)
C
C     AUTHOR  : DAN BROOKES
C     COMPANY: AIT CORP.
C     DATE    : 1993
C
C     THIS PROGRAM  IS FOR SIMULATING  THE ANTENNA
C     PATTERN  OF AN E-PLANE  SECTORAL  HORN PAIR IN THE
C     H-PLANE DIRECTION  (IE.PERPENDICULAR   TO THE
C     DIRETION  OF THE E FIELD IN THE APERTURE,  ASSUMING
C    A SPHERICAL  WAVE SOURCE  MOVEABLE  ALONG A PLANE
C     LOCATED  A DISTANCE  Z FROM  THE RECEIVER  PHASE
C     CENTRE
C
C     Inputs:  hrx  - receiver element  height (midpoint  of
C                  element  pair)
C            htarg- height of reflector or beacon  source
C            z    - horizontal  distance  of target  or beacon
C                  from receiver
C            theta- azimuthal  angle  from boresight
C
C      Outputs: sigd- complex valued signal for 'direct' ray
c            sigi- complex  valued  signal for 'indirect' ray
C
      REAL*8  X,T1,T2,Z,FREQ,RHO1,A,B1,WAVN,PI,PHZ,DIELRL
      REAL*8  Y,Y1,Y2,BETA,IM,ANGLE1,ANGLE2,PISQ,RL,A1
      REAL*8  ANGLE,AMPTOT,AMP1,AMP2,R1,R2,COS1,SWH
      REAL*8  THETA1,THETA2,THETA,PHASE,HRX,HTARG,KX1
      REAL*8  SIN1,PHI1,PHI2,KX2,KY1,KY2,DIELIM,WVL
      REAL  CF1,SF1,CF2,SF2,CT1,ST1,CF1P,SF1P,CF2P,SF2P,CT2,ST2
      COMPLEX*16  F,SIG1,SIG2,SIGI,SIGD,DIELSR,CR1
      COMPLEX*16  EPHI1,EPHI2,ET1,ET2,ETHETA1,ETHETA2
      COMPLEX  F1,F2
      INTEGER  K
      RHO1=.25D0   ! FLANGE  LENGTH  FOR  HORN
      A1=.0625D0     ! FLANGE  WIDTH
C       B1=.04D0   ! FLANGE  HEIGHT
      B1=.1        ! FLANGE  HEIGHT
      DELTA=.0625D0 ! DISTANCE  BETWEEN  APERTURE  CENTERS
```

```
C                 OF HORN PAIR
      PI=4.0D0*DATAN(1.0D0)
      WAVN=2.D0*PI*FREQ/.2998D0
      DIELSR=CDSQRT(DCMPLX(44.4D0,-40.9D0))
      DIELRL=DREAL(DIELSR)*2D0
      DIELIM=DIMAG(DIELSR)*2D0
C
C      TO CALCULATE THE SIGNAL FROM THE 'DIRECT' RAY
C
       Y=HTARG-HRX
       Y1=Y+DELTA/2.D0
       Y2=Y-DELTA/2.D0
       R1=DSQRT(Z**2+Y1**2)
       R1P=DSQRT((Z*DSIND(THETA))**2+Y1**2)
       R2P=DSQRT((Z*DSIND(THETA))**2+Y2**2)
       R2=DSQRT(Y2**2+Z**2)
       THETA1=DABS(DATAND(R1P/(Z*DCOSD(THETA))))
       THETA2=DABS(DATAND(R2P/(Z*DCOSD(THETA))))
       IF(Y1.NE.0.OR.THETA.NE.0)THEN
        PHI1=DATAN2D(Z*DSIND(THETA),Y1)
       ELSE
        PHI1=0.D0
       END IF
       IF(Y2.NE.0.OR.THETA.NE.0)THEN
        PHI2=DATAN2D(Z*DSIND(THETA),Y2)
       ELSE
        PHI2=0.D0
       END IF
       KX1=WAVN*DSIND(THETA1)*DCOSD(PHI1)
       KX2=WAVN*DSIND(THETA2)*DCOSD(PHI2)
       KY1=WAVN*DSIND(THETA1)*DSIND(PHI1)
       KY2=WAVN*DSIND(THETA2)*DSIND(PHI2)
       ALPHA=1.D0/DSQRT(PI*WAVN*RHO1)
       T11=ALPHA*(-WAVN*B1/2-KY1*RHO1)
       T21=ALPHA*(WAVN*B1/2-KY1*RHO1)
       T12=ALPHA*(-WAVN*B1/2-KY2*RHO1)
       T22=ALPHA*(WAVN*B1/2-KY2*RHO1)
       CALL FRESNEL(T21,CF2,SF2)
       CALL FRESNEL(T11,CF1,SF1)
       CALL FRESNEL(T22,CF2P,SF2P)
       CALL FRESNEL(T12,CF1P,SF1P)
      CT1=(CF2-CF1)
      ST1=(SF2-SF1)
      F1=CMPLX(1,0)
      F1=CMPLX(CT1,ST1)
      CT2=(CF2P-CF1P)
      ST2=(SF2P-SF1P)
      F2=CMPLX(1,0)
      F2=CMPLX(CT2,ST2)
      PISQ=PI**2/4
      BETA=(KX1*A1/2.D0)**2-PISQ
      IF(BETA.NE.0)THEN
        AMP1=COS(KX1*A1/2.D0)/BETA
       ELSE
        AMP1=1.0D0/PI
       END IF
      BETA=(KX2*A1/2.D0)**2-PISQ
      IF(BETA.NE.0)THEN
        AMP2=COS(KX2*A1/2.D0)/BETA
      ELSE
        AMP2=1.0D0/PI
      END IF
      AMP1=AMP1*(1.D0+DCOSD(THETA1))/R1
      AMP2=AMP2*(1.D0+DCOSD(THETA2))/R2
C
C CALCULATE TOTAL E SIG. AMPL FOR FIRST HALF OF
C HORN-PAIR
C
      COS1=DCOS(WAVN*R1)
      SIN1=-DSIN(WAVN*R1)
      ETHETA1=DCMPLX(COS1,SIN1)
      EPHI1=DCMPLX(COS1,SIN1)
      BETA=KY1**2*RHO1/(2.D0*WAVN)
      COS1=DCOS(BETA)
      SIN1=DSIN(BETA)
      ETHETA1=ETHETA1*DCMPLX(COS1,SIN1)
      ETHETA1=ETHETA1*DCMPLX(0.D0,-1.D0)*F1*AMP1
      EPHI1=EPHI1*DCMPLX(COS1,SIN1)*
    1 DCMPLX(0.D0,-1.D0)*F1*AMP1
      ETHETA1=ETHETA1*DSINd(PHI1)
      ephi1=ephi1*dabs(dcosD(phi1))!  be aware of ad hoc fix
C                                     here (dabs)
```

```
      IF(PHI1.EQ.90.D0)THEN
        PHASE=DATAN2(DIMAG(ETHETA1),DREAL(ETHETA1))
      ELSE
        PHASE=DATAN2(DIMAG(EPHI1),DREAL(EPHI1))
      END IF
      ET1=CDSQRT(ETHETA1*DCONJG(ETHETA1)+EPHI1*
     1  DCONJG(EPHI1))
      COS1=DCOS(PHASE)
      SIN1=DSIN(PHASE)
      ET1=ET1*DCMPLX(COS1,SIN1)
c
c calculate total E sig. ampl for second half of horn pair
c
      COS1=DCOS(WAVN*R2)
      SIN1=-DSIN(WAVN*R2)
      ETHETA2=DCMPLX(COS1,SIN1)
      EPHI2=DCMPLX(COS1,SIN1)
      BETA=KY2**2*RHO1/(2.D0*WAVN)
      COS1=DCOS(BETA)
      SIN1=DSIN(BETA)
      ETHETA2=ETHETA2*DCMPLX(COS1,SIN1)
      ETHETA2=ETHETA2*DCMPLX(0.D0,-1.D0)*F2*AMP2
      EPHI2=EPHI2*DCMPLX(COS1,SIN1)*
     1  DCMPLX(0.D0,-1.D0)*F2*AMP2
      ETHETA2=ETHETA2*DSINd(PHI2)
      EPHI2=EPHI2*DABS(DCOSd(PHI2))    ! AD HOC FIX
C                                        HERE (DABS)
      IF(PHI2.EQ.90.D0)THEN
       PHASE=DATAN2(DIMAG(ETHETA2),DREAL(ETHETA2))
      ELSE
       PHASE=DATAN2(DIMAG(EPHI2),DREAL(EPHI2))
      END IF
      et2=cdsqrt(etheta2*Dconjg(etheta2)+ephi2*Dconjg(ephi2))
      cos1=dcos(phase)
      sin1=dsin(phase)
      et2=et2*dcmplx(cos1,sin1)
C
C now to get the resultant E signal amplitude for the direct ray
C by adding the results from both halves of the horn-pair
C
      SIGD=ET1+ET2
```

```
C
C     to calculate the signal from the 'indirect' ray
C
       Y=HTARG+HRX
       Y1=Y-DELTA/2.D0
       Y2=Y+DELTA/2.D0
       R1=DSQRT(Z**2+Y1**2)
       R1P=DSQRT((Z*DSIND(THETA))**2+Y1**2)
       R2P=DSQRT((Z*DSIND(THETA))**2+Y2**2)
       R2=DSQRT(Y2**2+Z**2)
       THETA1=DABS(DATAND(R1P/(Z*DCOSD(THETA))))
       THETA2=DABS(DATAND(R2P/(Z*DCOSD(THETA))))
       PHI1=DATAN2D(Z*DSIND(THETA),-Y1)
       PHI2=DATAN2D(Z*DSIND(THETA),-Y2)
       KX1=WAVN*DSIND(THETA1)*DCOSD(PHI1)
       KX2=WAVN*DSIND(THETA2)*DCOSD(PHI2)
       KY1=WAVN*DSIND(THETA1)*DSIND(PHI1)
       KY2=WAVN*DSIND(THETA2)*DSIND(PHI2)
       ALPHA=1.D0/DSQRT(PI*WAVN*RHO1)
       T11=ALPHA*(-WAVN*B1/2-KY1*RHO1)
       T21=ALPHA*(WAVN*B1/2-KY1*RHO1)
       T12=ALPHA*(-WAVN*B1/2-KY2*RHO1)
       T22=ALPHA*(WAVN*B1/2-KY2*RHO1)
       CALL FRESNEL(T21,CF2,SF2)
       CALL FRESNEL(T11,CF1,SF1)
       CALL FRESNEL(T22,CF2P,SF2P)
       CALL FRESNEL(T12,CF1P,SF1P)
       CT1=(CF2-CF1)
       ST1=(SF2-SF1)
       F1=CMPLX(1,0)
       F1=CMPLX(CT1,ST1)
       CT2=(CF2P-CF1P)
       ST2=(SF2P-SF1P)
       F2=CMPLX(1,0)
       F2=CMPLX(CT2,ST2)
       PISQ=PI**2/4
       BETA=(KX1*A1/2.D0)**2-PISQ
       IF(BETA.NE.0)THEN
         AMP1=COS(KX1*A1/2.D0)/BETA
       ELSE
         AMP1=1.0D0/PI
```

```
      END IF
      BETA=(KX2*A1/2.D0)**2-PISQ
      IF(BETA.NE.0)THEN
        AMP2=COS(KX2*A1/2.D0)/BETA
      ELSE
        AMP2=1.0D0/PI
      END IF
      AMP1=AMP1*(1.D0+DCOSD(THETA1))/R1
      AMP2=AMP2*(1.D0+DCOSD(THETA2))/R2
C
C calculate total E sig. ampl of indirect signal for first half of
C horn-pair
c
      COS1=DCOS(WAVN*R1)
      SIN1=-DSIN(WAVN*R1)
      ETHETA1=DCMPLX(COS1,SIN1)
      EPHI1=DCMPLX(COS1,SIN1)
      BETA=KY1**2*RHO1/(2.D0*WAVN)
      COS1=DCOS(BETA)
      SIN1=DSIN(BETA)
      ETHETA1=ETHETA1*DCMPLX(COS1,SIN1)
      ETHETA1=ETHETA1*DCMPLX(0.D0,-1.D0)*F1*AMP1
      EPHI1=EPHI1*DCMPLX(COS1,SIN1)*DCMPLX(0.D0,-1.D0)
     1  *F1*AMP1
      ETHETA1=ETHETA1*DSIND(PHI1)
      EPHI1=EPHI1*DCOSD(PHI1)
      IF(PHI1.EQ.90.D0)THEN
        PHASE=DATAN2(DIMAG(ETHETA1),DREAL(ETHETA1))
      ELSE
        PHASE=DATAN2(DIMAG(EPHI1),DREAL(EPHI1))
      END IF
      ET1=CDSQRT(ETHETA1*dCONJG(ETHETA1)+
     1  EPHI1*dCONJG(EPHI1))
      COS1=DCOS(PHASE)
      SIN1=DSIN(PHASE)
      ET1=ET1*DCMPLX(COS1,SIN1)

c
c     the angle of the indirect ray wrt to the reflecting
C     surface for the first half of the horn pair is angle1
C     where:
```

```
c
      ANGLE1=DATAND(Y1/Z)
      call DREFCO  ( ANGLE1,FREQ,CR1,DIELRL,DIELIM,SWH)
      ET1=ET1*CR1
c
c calculate total E sig. ampl of indirect signal for second half
C  of horn-pair
c
      COS1=DCOS(WAVN*R2)
      SIN1=-DSIN(WAVN*R2)
      ETHETA2=DCMPLX(COS1,SIN1)
      EPHI2=DCMPLX(COS1,SIN1)
      BETA=KY2**2*RHO1/(2.D0*WAVN)
      COS1=DCOS(BETA)
      SIN1=DSIN(BETA)
      ETHETA2=ETHETA2*DCMPLX(COS1,SIN1)
      ETHETA2=ETHETA2*DCMPLX(0.D0,-1.D0)*F2*AMP2
      EPHI2=EPHI2*DCMPLX(COS1,SIN1)*DCMPLX(0.D0,-1.D0)
     1  *F2*AMP2
      ETHETA2=ETHETA2*DSIND(PHI2)
      EPHI2=EPHI2*DCOSD(PHI2)
      IF(PHI1.EQ.90.D0)THEN
        PHASE=DATAN2(DIMAG(ETHETA1),DREAL(ETHETA1))
      ELSE
        PHASE=DATAN2(DIMAG(EPHI1),DREAL(EPHI1))
      END IF
      ET2=CDSQRT(ETHETA2*dCONJG(ETHETA2)+
     1  EPHI2*dCONJG(EPHI2))
      COS1=DCOS(PHASE)
      SIN1=DSIN(PHASE)
      ET2=ET2*DCMPLX(COS1,SIN1)
C
C       the angle of the indirect ray wrt to the reflecting
C       surface for the second half of the horn pair is angle2
C       where:
C
      ANGLE2=DATAND(Y2/Z)
      CALL drefco ( ANGLE2,FREQ,CR1,DIELRL,DIELIM,SWH)
      ET2=ET2*CR1
```

```
C
C NOW TO GET THE RESULTANT e SIGNAL AMPLITUDE FOR THE
C INDIRECT C RAY BY ADDING THE RESULTS FROM BOTH
C HALVES OF THE HORN-PAIR
C
      SIGI=ET1+ET2
     RETURN
     END
```

```
      SUBROUTINE  DREFCO  ( GAMMA,freq1,cr1,dielrl,dielim,swh)
C
C      AUTHOR  : DAN BROOKES
C      COMPANY: AIT CORP.
C      DATE    : 1993
C
C      *** REFLECTION  COEFFICIENT  ***
C      this reflection coefficient assumes horizontal polarization
C      INPUT :
C      GAMMA  =  GRAZING  ANGLE  (RADIANS)
C
C      OUTPUT  :
C      CR1 = CARTESIAN  FORM  OF  REFLECTION  COEFF.  --|
C
C      CONSTANTS  :
C      DIELRL  = 2*(REAL  PART  OF  SQRT  OF  COMPLEX
C               DIELEC.  CONST.)
C      DIELIM  = 2*(IMAG.  PART  OF  SQRT  OF  COMPLEX  DIELEC.
C               CONST.)
C      WVL     = WAVELENGTH
C      SWH     = SIGNIFICANT  WAVE  HEIGHT
C      PI      = 3.14159...
C
      IMPLICIT  NONE
      INTEGER           istp,FREQ
C
      COMPLEX*16           DIELSR,CR1
C
C     -------------------------------------------------------------
C
      REAL*8            WVL,PSI,SWH,DIELRL,DIELIM,ROUGH
      REAL*8            RHFACTOR,freq1,SRF,PI,GAMMA
C
      PI=4.D0*DATAN(1.D0)
      wvl=.2998d0/freq1
      IF(ISTP.eq.0)THEN
        istp=1
        DIELSR  = dCMPLX(DIELRL/2.d0,DIELIM/2.d0)
        RHFACTOR=SWH/(4.d0*wvl)
      END IF
C
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C THE FOLLOWING  FORMULA  GIVES THE APPROXIMATE
C REFLECTION  COEFFICIENT  FOR HORIZONTAL  POLARIZATION
C OF THE E VECTOR
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
   CR1  = (dsin(GAMMA)-DIELSR)/(dsin(GAMMA)+DIELSR)
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    Note: the corresponding  equation  for vertical
C          polarization  would be:
C
C  cr1=(dsin(gamma)*dielsr-1.d0)
C                   /(dsin(gamma)*dielsr+1.d0)
C
CCCCCCCCCCCCCCCCCC CCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    CALCULATE  APPARENT  SURFACE  ROUGHNESS
C
   ROUGH   = DSIN(GAMMA)*RHFACTOR
C
C    CALCULATE  THEORETICAL  SURFACE  ROUGHNESS  FACTOR
C
   IF (ROUGH   .LT. .1d0)
  1SRF  = dEXP(-8.d0*(PI*ROUGH)**2)
C
C     SRF FOLLOWS  THEORETICAL   CURVE
C
   IF (ROUGH   .GE. .1d0)
  1SRF  =dEXP(-(.165d0*ROUGH**2   + 7.412d0*ROUGH   + .0468d0))
C
C     SRF FALLS LESS RAPIDLY  THAN  THEOR.
C
C    MODIFY  REFL  COEFF BY SURFACE  ROUGHNESS  FACTOR
C
   CR1  = CR1*SRF
   RETURN
   END
```

```
      SUBROUTINE  FRESNEL(X1,CF2,SF2)
C
C     AUTHOR  : DAN BROOKES
C     COMPANY: AIT CORP.
C     DATE    : 1993
C
C    THIS SUBROUTINE  CALCULATES  THE FRESNEL COSINE AND
C    SINE INTEGRALS  USING A SERIES EXPANSION SOLUTION IN
C    DOUBLE  PRECISION  IT IS USEFUL  ONLY UP TO VALUES OF
C    X1=5.0
C
     REAL  CF2,SF2
     REAL*8  X,CF,SF,PI,CF1,SF1,REM1,REM2,CF0,SF0
     PI=4.0D0*DATAN(1.0D0)
     X=X1*SQRT(PI/2D0)
     SF=0D0
     CF=0D0
     I=1
2    CONTINUE
      CF0=CF
      SF0=SF
      CF1=1D0
      SF1=1D0
      K=3+4*(I-1)
      IF(2*(I-1)+1.GT.1)THEN
      DO  L=2*(I-1)+1,2,-1
       IF(L.GT.1)THEN
        SF1=SF1*X*X/L
       END IF
       IF(L-1.GE.1)THEN
        CF1=CF1*X*X/(L-1)
       END IF
      END DO
      END IF
      REM1=DSQRT(2.D0/PI)*X**3*SF1*(-1)**(I-1)/K
      SF=SF+REM1
      K=1+4*(I-1)
      REM2=DSQRT(2.D0/PI)*X*CF1*(-1)**(I-1)/K
      CF=CF+REM2
      I=I+1
     IF(ABS(SF0-SF).GT.1D-6)GOTO  2
```

```
CF2=CF
SF2=SF
RETURN
END
```

```
      SUBROUTINE  BEAMPAT2(HRX,HTARG,Z,SIGD,SIGI,FREQ,
     1                THETA,N,SWH)
C
C     AUTHOR  : DAN BROOKES
C     COMPANY: AIT CORP.
C     DATE    : 1993
C
C
C     The function of this subroutine is to caluculate the
C     theoretical beam pattern for each element of a horizontal
C     array consisting of Narda 640 standard gain pyramidal horns.
C
C     INPUTS:
C            HRX    - height of antenna element
C            HTARG  - height of radar source (target, jammer
C                 etc.)
C            Z      - horizontal range to radar source.
C            FREQ   - frequency of source in GHz
C            THETA  - azimuth angle of source from boresight
C            N      - element number (1,2,...8)
C            SWH    - significant wave height
C
C     OUTPUTS:
C            SIGD   - estimated complex signal for direct ray
C            SIGI   - estimated complex signal for reflected ray
C
C
      REAL*8  KX,KX1,KX2,KY,RHO1,RHO2,Z,A1,B1,A,B,E,PE
      REAL*8  DY,RI,THETAR,THETA,PHASE1,RD,DIELIM,DX
      REAL*8  WAVN,PI,R,T1,T2,T11,T12,T21,T22,PHI1,THETA1
      REAL*8  FREQ,CF1,CF2,CT,CT1,CT2,ST,ST1,ST2,PHASE2
      REAL*8  AMP1,AMP2,PHASE,DIELRL,HRX,SWH,ZN,HTARG
      COMPLEX*16  F,F1,F2,C1,C2,ETHETAD,ETHETAI,EPHID,EPHII
      COMPLEX*16  CR1,DIELSR,SIGD,SIGI
      PI=4.D0*DATAN(1.D0)
      E=1.D0/7.D0 !SEPARATION  OF ARRAY  ELEMENTS
      A1=7.86D-2 !MEASUREMENTS  ARE  IN METRES
      B1=5.95D-2
      A=2.54D-2
      B=1.27D-2
      C=12.86D-2
      DIELSR=CDSQRT(DCMPLX(44.4D0,-40.9D0))
      DIELRL=DREAL(DIELSR)*2D0
      DIELIM=DIMAG(DIELSR)*2D0
      WAVN=2*PI*FREQ/.2998D0
      RHO1=B1*C/(B1-B)
      RHO2=A1*C/(A1-A)
      DY=Z*DSIND(THETA)+DFLOAT(2*N-9)*E/2.D0
      DX=HTARG-HRX
      IF(DY.NE.0.D0.OR.DX.NE.0.D0)THEN
        PHI1=DATAN2D(DY,DX)
      ELSE
        PHI1=0.D0
      END IF
      ZN=(Z**2+(DFLOAT(2*N-9)*E/2.D0)**2+
     * DFLOAT(2*N-9)*E*Z*DSIND(THETA))
      ZN=DSQRT(ZN)
      THETA1=DATAND(DSQRT(DY**2+DX**2)/
     1 (Z*DCOSD(THETA)))
      RD=DSQRT(ZN**2+DX**2)
      KX1=WAVN*DSIND(THETA1)*DCOSD(PHI1)+PI/A1
      KX2=WAVN*DSIND(THETA1)*DCOSD(PHI1)-PI/A1
      KY=WAVN*DSIND(THETA1)*DSIND(PHI1)
      ALPHA1=1.D0/DSQRT(PI*WAVN*RHO2)
      ALPHA2=1.D0/DSQRT(PI*WAVN*RHO1)
      T1=ALPHA2*(-WAVN*B1/2-KY*RHO1)
      T2=ALPHA2*(WAVN*B1/2-KY*RHO1)
      T11=ALPHA1*(-WAVN*A1/2-KX1*RHO2)
      T12=ALPHA1*(WAVN*A1/2-KX1*RHO2)
      T21=ALPHA1*(-WAVN*A1/2-KX2*RHO2)
      T22=ALPHA1*(WAVN*A1/2-KX2*RHO2)
      IF(DABS(T1).GT.5.D0)TYPE*,'T1  TOO LARGE  !'
      IF(DABS(T2).GT.5.D0)TYPE*,'T2  TOO LARGE  !'
      IF(DABS(T11).GT.5.D0)TYPE*,'T11  TOO LARGE  !'
      IF(DABS(T12).GT.5.D0)TYPE*,'T12  TOO LARGE  !'
      IF(DABS(T21).GT.5.D0)TYPE*,'T21  TOO LARGE  !'
      IF(DABS(T22).GT.5.D0)TYPE*,'T22  TOO LARGE  !'
      call fresnel(T1,cf1,sf1)
      call fresnel(T2,cf2,sf2)
      CT=CF2-CF1
      ST=SF2-SF1
      F=DCMPLX(CT,ST)
      CALL FRESNEL(T1,CF1,SF1)
      CALL FRESNEL(T2,CF2,SF2)
      CT=CF2-CF1
      ST=SF2-SF1
      F=DCMPLX(CT,-ST)
      CALL FRESNEL(T11,CF1,SF1)
      CALL FRESNEL(T12,CF2,SF2)
      CT1=CF2-CF1
      ST1=SF2-SF1
      F1=DCMPLX(CT1,-ST1)
      CALL FRESNEL(T21,CF1,SF1)
      CALL FRESNEL(T22,CF2,SF2)
      CT2=CF2-CF1
      ST2=SF2-SF1
      F2=DCMPLX(CT2,-ST2)
      PHASE1=KX1**2*RHO1/(2.D0*WAVN)
      PHASE2=KX2**2*RHO1/(2.D0*WAVN)
      COS1=DCOS(PHASE1)
      SIN1=DSIN(PHASE1)
      C1=DCMPLX(COS1,SIN1)*F1
      COS1=DCOS(PHASE2)
      SIN1=DSIN(PHASE2)
      C1=C1+DCMPLX(COS1,SIN1)*F2
      PHASE1=KY**2*RHO2/(2.D0*WAVN)
      COS1=DCOS(PHASE1)
      SIN1=DSIN(PHASE1)
      C2=DCMPLX(COS1,SIN1)*F
      PHASE1=WAVN*RD
      COS1=DCOS(PHASE1)
      SIN1=DSIN(PHASE1)
      AMP1=(1.D0+DCOSD(THETA1))/RD
      AMP2=dabs(DCOSD(PHI1))*AMP1
      AMP1=dabs(DSIND(PHI1))*AMP1
      ETHETAD=DCMPLX(0.D0,1.D0)*DCMPLX(COS1,-SIN1)*
     1 C1*C2*AMP1
      EPHID=DCMPLX(0.D0,1 .D0)*DCMPLX(COS1,-SIN1)*C1*C2*AMP2
C
C     NOW TO CALCULATE THE TOTAL FIELD STRENGTH FOR C
C     THE DIRECT SIGNAL
C
```

```
C
      AMP1=CDSQRT(ETHETAD*CONJG(ETHETAD)+
     1  EPHID*CONJG(EPHID))
      IF(PHI1.NE.0.D0)THEN
        PHASE=DATAN2(DIMAG(ETHETAD),DREAL(ETHETAD))
      ELSE
        PHASE=DATAN2(DIMAG(EPHID),DREAL(EPHID))
      END IF
      COS1=DCOS(PHASE)
      SIN1=DSIN(PHASE)
      SIGD=AMP1*DCMPLX(COS1,SIN1)
C
C
C
C
C     NOW TO DO THE CALCULATIONS  FOR THE INDIRECT
C     SIGNAL
C
      DX=-(HTARG+HRX)
      IF(DY.NE.0.OR.DX.NE.0)THEN
        PHI1=DATAN2D(DY,DX)
      ELSE
        PHI1=0.D0
      END IF
      RI=DSQRT(ZN**2+DX**2)
      THETA1=DATAND(DSQRT(DY**2+DX**2)/
     1  (Z*DCOSD(THETA)))
      THETAR=DATAN((HTARG+HRX)/ZN)
      KX1=WAVN*DSIND(THETA1)*DCOSD(PHI1)+PI/A1
      KX2=WAVN*DSIND(THETA1)*DCOSD(PHI1)-PI/A1
      KY=WAVN*DSIND(THETA1)*DSIND(PHI1)
      ALPHA1=1.D0/DSQRT(PI*WAVN*RHO2)
      ALPHA2=1.D0/DSQRT(PI*WAVN*RHO1)
      T1=ALPHA2*(-WAVN*B1/2-KY*RHO1)
      T2=ALPHA2*(WAVN*B1/2-KY*RHO1)
      T11=ALPHA1*(-WAVN*A1/2-KX1*RHO2)
      T12=ALPHA1*(WAVN*A1/2-KX1*RHO2)
      T21=ALPHA1*(-WAVN*A1/2-KX2*RHO2)
      T22=ALPHA1*(WAVN*A1/2-KX2*RHO2)
      IF(DABS(T1).GT.5.D0)TYPE*,'T1  TOO  LARGE  !'
      IF(DABS(T2).GT.5.D0)TYPE*,'T2  TOO  LARGE  !'
IF(DABS(T11).GT.5.D0)TYPE*,'T11  TOO  LARGE  !'
IF(DABS(T12).GT.5.D0)TYPE*,'T12  TOO  LARGE  !'
IF(DABS(T21).GT.5.D0)TYPE*,'T21  TOO  LARGE  !'
IF(DABS(T22).GT.5.D0)TYPE*,'T22  TOO  LARGE  !'
CALL FRESNEL(T1,CF1,SF1)
CALL FRESNEL(T2,CF2,SF2)
CT=CF2-CF1
ST=SF2-SF1
F=DCMPLX(CT,ST)
CALL FRESNEL(t1,CF1,SF1)
CALL FRESNEL(t2,CF2,SF2)
CT=CF2-CF1
ST=SF2-SF1
F=DCMPLX(CT,-ST)
CALL FRESNEL(t11,CF1,SF1)
CALL FRESNEL(t12,CF2,SF2)
CT1=CF2-CF1
ST1=SF2-SF1
F1=DCMPLX(CT1,-ST1)
CALL FRESNEL(t21,CF1,SF1)
CALL FRESNEL(t22,CF2,SF2)
CT2=CF2-CF1
ST2=SF2-SF1
F2=DCMPLX(CT2,-ST2)
PHASE1=KX1**2*RHO1/(2.D0*WAVN)
PHASE2=KX2**2*RHO1/(2.D0*WAVN)
COS1=DCOS(PHASE1)
SIN1=DSIN(PHASE1)
C1=DCMPLX(COS1,SIN1)*F1
COS1=DCOS(PHASE2)
SIN1=DSIN(PHASE2)
C1=C1+DCMPLX(COS1,SIN1)*F2
PHASE1=KY**2*RHO2/(2.D0*WAVN)
COS1=DCOS(PHASE1)
SIN1=DSIN(PHASE1)
C2=DCMPLX(COS1,SIN1)*F
PHASE1=WAVN*RI
COS1=DCOS(PHASE1)
SIN1=DSIN(PHASE1)
AMP1=(1.D0+DCOSD(THETA1))/RI
AMP2=dabs(DCOSD(PHI1))*AMP1
```

```
      AMP1=dabs(DSIND(PHI1))*AMP1
      ETHETAI=DCMPLX(0.D0,1.D0)*DCMPLX(COS1,-SIN1)*
     1 C1*C2*AMP1
      EPHII=DCMPLX(0.D0,1.D0)*DCMPLX(COS1,-SIN1)*C1*C2*AMP2
C
C      NOW CALCULATE TOTAL FIELD FOR INDIRECT RAY AND
C     COMBINE ITS PHASE WITH THE PHASE DUE TO REFLECTION
C
      AMP1=CDSQRT(ETHETAI*CONJG(ETHETAI)
     1 +EPHII*CONJG(EPHIi))
      IF(PHI1.NE.0.D0)THEN
        PHASE=DATAN2(DIMAG(ETHETAI),DREAL(ETHETAI))
      ELSE
        PHASE=DATAN2(DIMAG(EPHII),DREAL(EPHII))
      END IF
      COS1=DCOS(PHASE)
      SIN1=DSIN(PHASE)
      SIGI=AMP1*DCMPLX(COS1,SIN1)
        CALL DREFCO(THETAR,FREQ,CR1,DIELRL,DIELIM,SWH)
      SIGI=SIGI*CR1
      RETURN
      END
      PROGRAM  DUMPFILE
C
C      Author  : Dan Brookes
C      Company: AIT Corp.
C      Date    : 1993
C
C      This program is for dumping the contents of a file onto a
C      monitor screen, in hexadecimal format.
C
      REAL RNGON,RNGOFF
      LOGICAL*1 IPT(512)
      CHARACTER  INFILE*80,STRING(256)*4
      INTEGER*2  RDATA(256)
      EQUIVALENCE  (IPT(1),RDATA(1))
      TYPE *,'ENTER THE INPUT FILENAME:'
      ACCEPT10,INFILE
10     FORMAT(A80)
      TYPE *,'ENTER THE START BLOCK:'
      ACCEPT*, STBL
      NBLOCK=NBLOCK+STBL
       OPEN(UNIT=76,FILE=infile,STATUS='OLD',FORM=
     1 'UNFORMATTED',ACCESS='DIRECT',RECL=128,
     1 ASSOCIATEVARIABLE=nblock)
11     READ(76,REC=nblock)  (IPT(I), I=1,512)
      NBLOCK=NBLOCK+STBL
C
       DO I=1,256
         ENCODE(4,147,string(i))rdata(i)
147       FORMAT(z4)
         DO K=1,4
           IF(STRING(I)(K:K).EQ.' ')STRING(I)(K:K)='0'
         END DO
       END DO
       DO I=1,16
         TYPE 111,(STRING(17+(I-1)*16-K),K=1,16)
111        FORMAT(2X,16(A4,X))
       END DO
       PAUSE
       GOTO 11
333    CONTINUE
       END
```

APPENDIX E
TABLE OF STATISTICS FOR FIGURE 5.2

Table E1

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
1	-20.0	0.425	0.652	0.535	0.056	128
1	-19.5	0.467	0.672	0.570	0.055	128
1	-19.0	0.424	0.658	0.536	0.058	128
1	-18.5	0.397	0.574	0.483	0.050	128
1	-18.0	0.351	0.534	0.432	0.050	128
1	-17.5	0.245	0.420	0.330	0.049	128
1	-17.0	0.142	0.329	0.232	0.050	128
1	-16.5	0.059	0.238	0.148	0.049	128
1	-16.0	0.024	0.198	0.118	0.049	128
1	-15.5	0.039	0.221	0.142	0.049	128
1	-15.0	0.085	0.264	0.177	0.052	128
1	-14.5	0.101	0.288	0.190	0.050	128
1	-14.0	0.022	0.195	0.109	0.049	128
1	-13.5	0.007	0.186	0.103	0.045	128
1	-13.0	0.026	0.205	0.126	0.049	128
1	-12.5	0.108	0.303	0.210	0.051	128
1	-12.0	0.201	0.406	0.295	0.049	128
1	-11.5	0.226	0.419	0.324	0.051	128
1	-11.0	0.211	0.391	0.298	0.051	128
1	-10.5	0.232	0.411	0.316	0.049	128
1	-10.0	0.221	0.421	0.333	0.050	128
1	-9.5	0.088	0.352	0.266	0.053	128
1	-9.0	0.069	0.274	0.180	0.048	128
1	-8.5	0.007	0.182	0.102	0.045	128
1	-8.0	0.011	0.168	0.100	0.047	128
1	-7.5	0.059	0.244	0.153	0.049	128
1	-7.0	0.128	0.298	0.214	0.050	128
1	-6.5	0.142	0.319	0.228	0.048	128
1	-6.0	0.184	0.352	0.262	0.043	128
1	-5.5	0.155	0.335	0.244	0.049	128
1	-5.0	0.137	0.307	0.217	0.050	128
1	-4.5	0.088	0.261	0.169	0.049	128
1	-4.0	0.014	0.199	0.111	0.049	128
1	-3.5	0.015	0.216	0.112	0.048	128
1	-3.0	0.069	0.233	0.141	0.048	128
1	-2.5	0.105	0.291	0.187	0.053	128
1	-2.0	0.099	0.291	0.191	0.050	128
1	-1.5	0.122	0.289	0.210	0.048	128
1	-1.0	0.111	0.283	0.194	0.049	128
1	-0.5	0.052	0.225	0.139	0.048	128
1	0.0	0.007	0.175	0.099	0.042	128
1	0.5	0.007	0.166	0.084	0.042	128
1	1.0	0.007	0.169	0.093	0.042	128
1	1.5	0.020	0.202	0.115	0.049	128
1	2.0	0.020	0.183	0.103	0.043	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
1	2.5	0.030	0.196	0.114	0.046	128
1	3.0	0.068	0.235	0.151	0.048	128
1	3.5	0.166	0.346	0.248	0.047	128
1	4.0	0.430	0.617	0.511	0.046	128
1	4.5	0.461	0.662	0.544	0.050	128
1	5.0	0.468	0.649	0.552	0.052	128
1	5.5	0.628	0.812	0.708	0.052	128
1	6.0	0.426	0.651	0.527	0.051	128
1	6.5	0.176	0.340	0.248	0.049	128
1	7.0	0.055	0.224	0.143	0.049	128
1	7.5	0.007	0.140	0.079	0.039	128
1	8.0	0.143	0.322	0.237	0.050	128
1	8.5	0.350	0.532	0.432	0.049	128
1	9.0	0.592	0.785	0.680	0.053	128
1	9.5	1.017	1.287	1.147	0.062	128
1	10.0	1.315	1.597	1.450	0.071	128
1	10.5	1.195	1.393	1.279	0.052	128
1	11.0	1.332	1.566	1.429	0.061	128
1	11.5	1.638	1.904	1.765	0.063	128
1	12.0	1.262	1.463	1.349	0.055	128
1	12.5	0.847	1.090	0.948	0.056	128
1	13.0	0.792	0.978	0.870	0.053	128
1	13.5	0.497	0.684	0.579	0.050	128
1	14.0	0.226	0.398	0.311	0.047	128
1	14.5	0.059	0.226	0.157	0.045	128
1	15.0	0.007	0.157	0.084	0.038	128
1	15.5	0.007	0.148	0.079	0.038	128
1	16.0	0.007	0.166	0.090	0.044	128
1	16.5	0.011	0.156	0.091	0.041	128
1	17.0	0.007	0.142	0.078	0.037	128
1	17.5	0.014	0.124	0.070	0.027	128
1	18.0	0.015	0.127	0.072	0.030	128
1	18.5	0.007	0.154	0.084	0.042	128
1	19.0	0.031	0.207	0.121	0.046	128
1	19.5	0.044	0.225	0.139	0.050	128
1	20.0	0.094	0.264	0.176	0.045	128
2	-20.0	0.011	0.186	0.100	0.046	128
2	-19.5	0.020	0.127	0.077	0.029	128
2	-19.0	0.007	0.156	0.089	0.038	128
2	-18.5	0.007	0.188	0.107	0.047	128
2	-18.0	0.011	0.196	0.107	0.048	128
2	-17.5	0.011	0.190	0.108	0.049	128
2	-17.0	0.015	0.209	0.109	0.050	128
2	-16.5	0.055	0.242	0.158	0.048	128
2	-16.0	0.122	0.344	0.226	0.052	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
2	-15.5	0.220	0.431	0.339	0.052	128
2	-15.0	0.419	0.622	0.525	0.056	128
2	-14.5	0.459	0.666	0.562	0.055	128
2	-14.0	0.300	0.499	0.394	0.053	128
2	-13.5	0.243	0.446	0.364	0.053	128
2	-13.0	0.229	0.431	0.336	0.053	128
2	-12.5	0.183	0.382	0.289	0.050	128
2	-12.0	0.083	0.293	0.198	0.054	128
2	-11.5	0.007	0.156	0.080	0.035	128
2	-11.0	0.011	0.171	0.092	0.041	128
2	-10.5	0.048	0.254	0.170	0.053	128
2	-10.0	0.105	0.293	0.216	0.051	128
2	-9.5	0.176	0.412	0.292	0.053	128
2	-9.0	0.164	0.367	0.272	0.055	128
2	-8.5	0.210	0.436	0.315	0.053	128
2	-8.0	0.200	0.415	0.311	0.055	128
2	-7.5	0.173	0.367	0.273	0.053	128
2	-7.0	0.153	0.350	0.254	0.050	128
2	-6.5	0.105	0.294	0.211	0.054	128
2	-6.0	0.059	0.283	0.175	0.056	128
2	-5.5	0.046	0.261	0.155	0.053	128
2	-5.0	0.011	0.238	0.145	0.051	128
2	-4.5	0.011	0.211	0.116	0.050	128
2	-4.0	0.011	0.172	0.099	0.043	128
2	-3.5	0.015	0.153	0.082	0.035	128
2	-3.0	0.020	0.157	0.076	0.024	128
2	-2.5	0.014	0.134	0.075	0.030	128
2	-2.0	0.007	0.167	0.096	0.047	128
2	-1.5	0.014	0.194	0.113	0.048	128
2	-1.0	0.053	0.245	0.150	0.051	128
2	-0.5	0.054	0.269	0.177	0.052	128
2	0.0	0.145	0.367	0.266	0.051	128
2	0.5	0.530	0.756	0.658	0.055	128
2	1.0	0.483	0.702	0.589	0.058	128
2	1.5	0.452	0.683	0.575	0.057	128
2	2.0	0.432	0.635	0.517	0.054	128
2	2.5	0.258	0.462	0.379	0.052	128
2	3.0	0.162	0.367	0.271	0.053	128
2	3.5	0.066	0.301	0.179	0.055	128
2	4.0	0.022	0.248	0.138	0.051	128
2	4.5	0.279	0.488	0.374	0.054	128
2	5.0	0.501	0.717	0.616	0.056	128
2	5.5	1.035	1.261	1.155	0.058	128
2	6.0	1.085	1.374	1.224	0.064	128
2	6.5	0.765	0.977	0.882	0.055	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
2	7.0	0.847	1.084	0.953	0.058	128
2	7.5	1.002	1.217	1.112	0.056	128
2	8.0	1.107	1.358	1.234	0.063	128
2	8.5	0.952	1.237	1.098	0.063	128
2	9.0	0.907	1.162	1.036	0.059	128
2	9.5	0.992	1.257	1.136	0.063	128
2	10.0	0.815	1.065	0.952	0.059	128
2	10.5	0.420	0.629	0.526	0.051	128
2	11.0	0.200	0.429	0.331	0.054	128
2	11.5	0.094	0.304	0.206	0.053	128
2	12.0	0.015	0.212	0.114	0.051	128
2	12.5	0.038	0.244	0.136	0.048	128
2	13.0	0.066	0.269	0.170	0.052	128
2	13.5	0.030	0.237	0.139	0.052	128
2	14.0	0.007	0.206	0.105	0.046	128
2	14.5	0.007	0.187	0.109	0.048	128
2	15.0	0.053	0.252	0.146	0.052	128
2	15.5	0.093	0.291	0.203	0.049	128
2	16.0	0.142	0.342	0.243	0.054	128
2	16.5	0.178	0.375	0.281	0.048	128
2	17.0	0.146	0.356	0.257	0.056	128
2	17.5	0.109	0.329	0.222	0.052	128
2	18.0	0.085	0.279	0.190	0.049	128
2	18.5	0.056	0.230	0.158	0.047	128
2	19.0	0.018	0.200	0.125	0.048	128
2	19.5	0.007	0.152	0.089	0.037	128
2	20.0	0.026	0.142	0.076	0.025	128
3	-20.0	0.025	0.305	0.177	0.078	128
3	-19.5	0.015	0.366	0.205	0.095	128
3	-19.0	0.021	0.368	0.226	0.100	128
3	-18.5	0.030	0.386	0.229	0.099	128
3	-18.0	0.046	0.421	0.253	0.102	128
3	-17.5	0.035	0.385	0.232	0.103	128
3	-17.0	0.007	0.366	0.203	0.099	128
3	-16.5	0.007	0.358	0.200	0.091	128
3	-16.0	0.011	0.307	0.188	0.087	128
3	-15.5	0.040	0.256	0.156	0.061	128
3	-15.0	0.035	0.283	0.177	0.066	128
3	-14.5	0.007	0.349	0.200	0.093	128
3	-14.0	0.007	0.321	0.184	0.090	128
3	-13.5	0.014	0.362	0.218	0.099	128
3	-13.0	0.022	0.348	0.210	0.095	128
3	-12.5	0.007	0.364	0.223	0.095	128
3	-12.0	0.007	0.345	0.203	0.099	128
3	-11.5	0.015	0.326	0.185	0.083	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
3	-11.0	0.036	0.259	0.163	0.058	128
3	-10.5	0.060	0.270	0.162	0.057	128
3	-10.0	0.046	0.269	0.163	0.054	128
3	-9.5	0.049	0.851	0.173	0.086	128
3	-9.0	0.040	0.263	0.161	0.053	128
3	-8.5	0.038	0.271	0.162	0.054	128
3	-8.0	0.073	0.234	0.154	0.041	128
3	-7.5	0.073	0.236	0.157	0.038	128
3	-7.0	0.039	0.273	0.162	0.058	128
3	-6.5	0.021	0.278	0.168	0.068	128
3	-6.0	0.018	0.317	0.193	0.071	128
3	-5.5	0.022	0.317	0.169	0.073	128
3	-5.0	0.015	0.300	0.167	0.076	128
3	-4.5	0.007	0.291	0.173	0.075	128
3	-4.0	0.015	0.344	0.195	0.091	128
3	-3.5	0.040	0.392	0.240	0.100	128
3	-3.0	0.090	0.482	0.302	0.113	128
3	-2.5	0.157	0.518	0.354	0.103	128
3	-2.0	0.163	0.538	0.368	0.106	128
3	-1.5	0.156	0.520	0.351	0.109	128
3	-1.0	0.128	0.501	0.328	0.113	128
3	-0.5	0.026	0.385	0.237	0.097	128
3	0.0	0.030	0.290	0.176	0.074	128
3	0.5	0.011	0.355	0.210	0.095	128
3	1.0	0.246	0.579	0.433	0.106	128
3	1.5	0.474	0.817	0.657	0.106	128
3	2.0	0.647	1.011	0.813	0.107	128
3	2.5	0.605	0.958	0.801	0.105	128
3	3.0	0.651	1.029	0.859	0.112	128
3	3.5	0.846	1.243	1.060	0.109	128
3	4.0	1.553	1.996	1.836	0.118	128
3	4.5	1.257	1.701	1.507	0.112	128
3	5.0	0.991	1.396	1.204	0.104	128
3	5.5	1.119	1.505	1.310	0.110	128
3	6.0	0.657	1.060	0.883	0.111	128
3	6.5	0.186	0.550	0.387	0.109	128
3	7.0	0.056	0.413	0.259	0.102	128
3	7.5	0.007	0.348	0.187	0.091	128
3	8.0	0.011	0.291	0.172	0.071	128
3	8.5	0.031	0.307	0.177	0.074	128
3	9.0	0.015	0.340	0.186	0.091	128
3	9.5	0.007	0.393	0.221	0.100	128
3	10.0	0.007	0.365	0.212	0.101	128
3	10.5	0.020	0.318	0.186	0.089	128
3	11.0	0.020	0.379	0.227	0.105	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
3	11.5	0.180	0.543	0.376	0.107	128
3	12.0	0.191	0.557	0.397	0.107	128
3	12.5	0.179	0.532	0.375	0.106	128
3	13.0	0.251	0.611	0.449	0.107	128
3	13.5	0.193	0.585	0.402	0.111	128
3	14.0	0.083	0.470	0.291	0.108	128
3	14.5	0.011	0.364	0.207	0.103	128
3	15.0	0.020	0.312	0.183	0.084	128
3	15.5	0.050	0.270	0.167	0.060	128
3	16.0	0.068	0.232	0.158	0.040	128
3	16.5	0.052	0.251	0.160	0.049	128
3	17.0	0.026	0.266	0.167	0.056	128
3	17.5	0.028	0.256	0.168	0.058	128
3	18.0	0.049	0.267	0.165	0.056	128
3	18.5	0.037	0.267	0.163	0.059	128
3	19.0	0.045	0.270	0.166	0.059	128
3	19.5	0.048	0.265	0.163	0.050	128
3	20.0	0.066	0.256	0.158	0.045	128
4	-20.0	0.011	0.151	0.088	0.029	128
4	-19.5	0.022	0.154	0.088	0.030	128
4	-19.0	0.007	0.129	0.070	0.030	128
4	-18.5	0.066	0.193	0.128	0.029	128
4	-18.0	0.116	0.259	0.184	0.032	128
4	-17.5	0.124	0.252	0.193	0.027	128
4	-17.0	0.118	0.254	0.188	0.031	128
4	-16.5	0.116	0.249	0.181	0.030	128
4	-16.0	0.144	0.272	0.213	0.030	128
4	-15.5	0.152	0.287	0.213	0.031	128
4	-15.0	0.164	0.287	0.230	0.032	128
4	-14.5	0.156	0.283	0.220	0.029	128
4	-14.0	0.072	0.201	0.143	0.027	128
4	-13.5	0.083	0.211	0.150	0.031	128
4	-13.0	0.063	0.199	0.141	0.029	128
4	-12.5	0.077	0.187	0.137	0.027	128
4	-12.0	0.046	0.171	0.110	0.029	128
4	-11.5	0.007	0.145	0.063	0.030	128
4	-11.0	0.007	0.071	0.040	0.014	128
4	-10.5	0.011	0.122	0.065	0.027	128
4	-10.0	0.031	0.164	0.101	0.029	128
4	-9.5	0.091	0.202	0.148	0.028	128
4	-9.0	0.084	0.210	0.154	0.029	128
4	-8.5	0.109	0.244	0.178	0.030	128
4	-8.0	0.133	0.259	0.196	0.028	128
4	-7.5	0.149	0.270	0.217	0.028	128
4	-7.0	0.210	0.350	0.284	0.031	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
4	-6.5	0.228	0.371	0.311	0.029	128
4	-6.0	0.332	0.442	0.396	0.028	128
4	-5.5	0.345	0.497	0.426	0.031	128
4	-5.0	0.366	0.474	0.421	0.027	128
4	-4.5	0.282	0.410	0.359	0.031	128
4	-4.0	0.191	0.334	0.253	0.030	128
4	-3.5	0.057	0.199	0.137	0.030	128
4	-3.0	0.064	0.167	0.114	0.025	128
4	-2.5	0.204	0.349	0.280	0.031	128
4	-2.0	0.391	0.514	0.458	0.027	128
4	-1.5	0.553	0.722	0.636	0.034	128
4	-1.0	0.761	0.920	0.854	0.033	128
4	-0.5	0.808	0.973	0.878	0.034	128
4	0.0	1.011	1.177	1.107	0.034	128
4	0.5	2.070	2.332	2.194	0.053	128
4	1.0	1.480	1.725	1.602	0.049	128
4	1.5	1.184	1.374	1.298	0.036	128
4	2.0	0.879	1.047	0.995	0.033	128
4	2.5	0.519	0.660	0.592	0.031	128
4	3.0	0.326	0.440	0.387	0.028	128
4	3.5	0.213	0.329	0.273	0.028	128
4	4.0	0.155	0.268	0.209	0.028	128
4	4.5	0.051	0.182	0.122	0.030	128
4	5.0	0.083	0.207	0.152	0.027	128
4	5.5	0.156	0.282	0.220	0.028	128
4	6.0	0.098	0.252	0.172	0.030	128
4	6.5	0.050	0.163	0.109	0.027	128
4	7.0	0.088	0.206	0.152	0.027	128
4	7.5	0.194	0.313	0.255	0.029	128
4	8.0	0.304	0.446	0.373	0.029	128
4	8.5	0.345	0.481	0.415	0.029	128
4	9.0	0.407	0.538	0.477	0.027	128
4	9.5	0.526	0.700	0.627	0.034	128
4	10.0	0.537	0.698	0.624	0.032	128
4	10.5	0.349	0.478	0.418	0.030	128
4	11.0	0.262	0.397	0.329	0.030	128
4	11.5	0.208	0.335	0.275	0.030	128
4	12.0	0.101	0.216	0.159	0.029	128
4	12.5	0.101	0.216	0.166	0.028	128
4	13.0	0.190	0.310	0.255	0.029	128
4	13.5	0.204	0.324	0.270	0.030	128
4	14.0	0.162	0.280	0.225	0.030	128
4	14.5	0.111	0.238	0.176	0.031	128
4	15.0	0.078	0.214	0.152	0.030	128
4	15.5	0.073	0.203	0.132	0.030	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
4	16.0	0.042	0.160	0.103	0.029	128
4	16.5	0.020	0.162	0.086	0.030	128
4	17.0	0.015	0.152	0.079	0.029	128
4	17.5	0.024	0.141	0.082	0.028	128
4	18.0	0.015	0.133	0.076	0.028	128
4	18.5	0.020	0.131	0.072	0.028	128
4	19.0	0.007	0.138	0.066	0.027	128
4	19.5	0.007	0.107	0.052	0.024	128
4	20.0	0.007	0.090	0.046	0.021	128
5	-20.0	0.020	0.241	0.148	0.061	128
5	-19.5	0.011	0.230	0.145	0.063	128
5	-19.0	0.007	0.200	0.121	0.053	128
5	-18.5	0.020	0.182	0.110	0.045	128
5	-18.0	0.030	0.192	0.107	0.042	128
5	-17.5	0.011	0.175	0.110	0.046	128
5	-17.0	0.011	0.200	0.115	0.053	128
5	-16.5	0.005	0.227	0.126	0.063	128
5	-16.0	0.011	0.205	0.127	0.057	128
5	-15.5	0.007	0.176	0.104	0.049	128
5	-15.0	0.030	0.162	0.103	0.037	128
5	-14.5	0.064	0.142	0.099	0.017	128
5	-14.0	0.037	0.159	0.099	0.029	128
5	-13.5	0.007	0.206	0.111	0.049	128
5	-13.0	0.005	0.215	0.123	0.058	128
5	-12.5	0.011	0.245	0.142	0.063	128
5	-12.0	0.011	0.249	0.153	0.069	128
5	-11.5	0.021	0.240	0.145	0.066	128
5	-11.0	0.020	0.245	0.154	0.064	128
5	-10.5	0.035	0.266	0.169	0.068	128
5	-10.0	0.074	0.294	0.200	0.068	128
5	-9.5	0.114	0.342	0.236	0.069	128
5	-9.0	0.107	0.328	0.234	0.064	128
5	-8.5	0.105	0.333	0.229	0.067	128
5	-8.0	0.076	0.310	0.208	0.064	128
5	-7.5	0.007	0.231	0.136	0.065	128
5	-7.0	0.059	0.132	0.094	0.017	128
5	-6.5	0.014	0.225	0.126	0.062	128
5	-6.0	0.135	0.368	0.273	0.064	128
5	-5.5	0.294	0.523	0.431	0.070	128
5	-5.0	0.430	0.662	0.568	0.069	128
5	-4.5	0.518	0.771	0.676	0.070	128
5	-4.0	0.594	0.824	0.731	0.072	128
5	-3.5	0.650	0.934	0.811	0.076	128
5	-3.0	0.650	0.894	0.775	0.068	128
5	-2.5	0.630	0.910	0.787	0.082	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
5	-2.0	0.532	0.765	0.660	0.071	128
5	-1.5	0.405	0.638	0.547	0.069	128
5	-1.0	0.320	0.553	0.443	0.069	128
5	-0.5	0.147	0.371	0.271	0.072	128
5	0.0	0.071	0.307	0.197	0.067	128
5	0.5	0.127	0.357	0.255	0.072	128
5	1.0	0.084	0.332	0.218	0.067	128
5	1.5	0.110	0.343	0.240	0.068	128
5	2.0	0.097	0.321	0.204	0.071	128
5	2.5	0.030	0.269	0.173	0.067	128
5	3.0	0.020	0.244	0.153	0.066	128
5	3.5	0.044	0.271	0.169	0.062	128
5	4.0	0.213	0.444	0.354	0.063	128
5	4.5	0.254	0.491	0.390	0.070	128
5	5.0	0.280	0.537	0.425	0.072	128
5	5.5	0.474	0.713	0.604	0.068	128
5	6.0	0.377	0.618	0.514	0.069	128
5	6.5	0.174	0.396	0.295	0.067	128
5	7.0	0.115	0.354	0.240	0.071	128
5	7.5	0.078	0.302	0.201	0.066	128
5	8.0	0.024	0.238	0.146	0.065	128
5	8.5	0.014	0.196	0.115	0.050	128
5	9.0	0.021	0.253	0.147	0.067	128
5	9.5	0.133	0.362	0.260	0.067	128
5	10.0	0.214	0.455	0.348	0.071	128
5	10.5	0.189	0.415	0.313	0.067	128
5	11.0	0.203	0.456	0.343	0.072	128
5	11.5	0.266	0.493	0.392	0.067	128
5	12.0	0.137	0.376	0.272	0.068	128
5	12.5	0.048	0.277	0.174	0.066	128
5	13.0	0.020	0.245	0.152	0.061	128
5	13.5	0.007	0.210	0.125	0.061	128
5	14.0	0.011	0.195	0.114	0.053	128
5	14.5	0.011	0.189	0.105	0.050	128
5	15.0	0.020	0.174	0.108	0.039	128
5	15.5	0.031	0.157	0.101	0.037	128
5	16.0	0.044	0.152	0.101	0.023	128
5	16.5	0.064	0.133	0.097	0.013	128
5	17.0	0.062	0.128	0.097	0.015	128
5	17.5	0.049	0.148	0.101	0.026	128
5	18.0	0.035	0.167	0.103	0.032	128
5	18.5	0.042	0.169	0.105	0.032	128
5	19.0	0.030	0.176	0.106	0.037	128
5	19.5	0.020	0.182	0.109	0.038	128
5	20.0	0.011	0.192	0.111	0.041	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
6	-20.0	0.007	0.144	0.080	0.039	128
6	-19.5	0.011	0.147	0.084	0.038	128
6	-19.0	0.007	0.147	0.077	0.034	128
6	-18.5	0.007	0.104	0.056	0.023	128
6	-18.0	0.014	0.084	0.053	0.016	128
6	-17.5	0.007	0.098	0.054	0.022	128
6	-17.0	0.007	0.118	0.066	0.031	128
6	-16.5	0.007	0.136	0.072	0.032	128
6	-16.0	0.018	0.161	0.098	0.036	128
6	-15.5	0.039	0.176	0.108	0.036	128
6	-15.0	0.111	0.243	0.175	0.038	128
6	-14.5	0.138	0.297	0.217	0.038	128
6	-14.0	0.138	0.280	0.202	0.039	128
6	-13.5	0.169	0.317	0.244	0.041	128
6	-13.0	0.200	0.332	0.267	0.038	128
6	-12.5	0.241	0.396	0.311	0.039	128
6	-12.0	0.231	0.390	0.308	0.041	128
6	-11.5	0.175	0.319	0.247	0.039	128
6	-11.0	0.073	0.242	0.163	0.038	128
6	-10.5	0.028	0.156	0.092	0.035	128
6	-10.0	0.083	0.218	0.148	0.036	128
6	-9.5	0.225	0.374	0.298	0.036	128
6	-9.0	0.352	0.513	0.435	0.039	128
6	-8.5	0.536	0.695	0.613	0.041	128
6	-8.0	0.728	0.861	0.779	0.039	128
6	-7.5	0.775	0.972	0.858	0.046	128
6	-7.0	0.887	1.047	0.958	0.039	128
6	-6.5	0.810	0.972	0.876	0.040	128
6	-6.0	0.809	0.973	0.887	0.041	128
6	-5.5	0.722	0.877	0.783	0.040	128
6	-5.0	0.584	0.732	0.640	0.040	128
6	-4.5	0.396	0.533	0.460	0.036	128
6	-4.0	0.217	0.353	0.281	0.038	128
6	-3.5	0.061	0.196	0.137	0.036	128
6	-3.0	0.015	0.136	0.083	0.033	128
6	-2.5	0.102	0.235	0.169	0.037	128
6	-2.0	0.149	0.294	0.214	0.038	128
6	-1.5	0.173	0.314	0.232	0.040	128
6	-1.0	0.151	0.308	0.228	0.041	128
6	-0.5	0.094	0.235	0.164	0.037	128
6	0.0	0.100	0.256	0.180	0.039	128
6	0.5	0.396	0.550	0.465	0.044	128
6	1.0	0.411	0.571	0.488	0.041	128
6	1.5	0.474	0.628	0.550	0.041	128
6	2.0	0.499	0.639	0.557	0.038	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
6	2.5	0.396	0.535	0.464	0.038	128
6	3.0	0.343	0.486	0.416	0.040	128
6	3.5	0.352	0.523	0.429	0.042	128
6	4.0	0.481	0.660	0.575	0.044	128
6	4.5	0.258	0.410	0.334	0.040	128
6	5.0	0.069	0.216	0.145	0.036	128
6	5.5	0.007	0.148	0.076	0.036	128
6	6.0	0.114	0.249	0.181	0.039	128
6	6.5	0.119	0.247	0.183	0.036	128
6	7.0	0.154	0.294	0.225	0.039	128
6	7.5	0.201	0.337	0.264	0.038	128
6	8.0	0.193	0.353	0.275	0.039	128
6	8.5	0.142	0.301	0.231	0.038	128
6	9.0	0.132	0.283	0.204	0.039	128
6	9.5	0.156	0.301	0.227	0.038	128
6	10.0	0.149	0.292	0.219	0.039	128
6	10.5	0.087	0.238	0.162	0.038	128
6	11.0	0.098	0.235	0.170	0.038	128
6	11.5	0.128	0.288	0.203	0.039	128
6	12.0	0.081	0.236	0.148	0.038	128
6	12.5	0.007	0.149	0.080	0.035	128
6	13.0	0.014	0.090	0.053	0.020	128
6	13.5	0.007	0.110	0.055	0.022	128
6	14.0	0.011	0.133	0.070	0.033	128
6	14.5	0.011	0.142	0.077	0.034	128
6	15.0	0.015	0.161	0.090	0.037	128
6	15.5	0.015	0.164	0.090	0.037	128
6	16.0	0.007	0.147	0.088	0.035	128
6	16.5	0.035	0.164	0.106	0.036	128
6	17.0	0.042	0.190	0.121	0.040	128
6	17.5	0.065	0.213	0.136	0.038	128
6	18.0	0.073	0.221	0.146	0.035	128
6	18.5	0.087	0.216	0.150	0.035	128
6	19.0	0.090	0.234	0.161	0.038	128
6	19.5	0.062	0.196	0.134	0.038	128
6	20.0	0.046	0.191	0.112	0.032	128
7	-20.0	0.007	0.081	0.037	0.017	128
7	-19.5	0.007	0.090	0.041	0.017	128
7	-19.0	0.015	0.093	0.059	0.016	128
7	-18.5	0.015	0.128	0.079	0.019	128
7	-18.0	0.087	0.186	0.140	0.020	128
7	-17.5	0.164	0.261	0.210	0.020	128
7	-17.0	0.178	0.281	0.239	0.021	128
7	-16.5	0.261	0.363	0.307	0.022	128
7	-16.0	0.340	0.466	0.407	0.024	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
7	-15.5	0.352	0.474	0.416	0.027	128
7	-15.0	0.333	0.448	0.401	0.022	128
7	-14.5	0.161	0.272	0.218	0.020	128
7	-14.0	0.025	0.113	0.070	0.018	128
7	-13.5	0.144	0.262	0.200	0.021	128
7	-13.0	0.293	0.394	0.359	0.020	128
7	-12.5	0.521	0.633	0.587	0.025	128
7	-12.0	0.693	0.842	0.775	0.035	128
7	-11.5	0.751	0.907	0.843	0.030	128
7	-11.0	0.780	0.922	0.849	0.030	128
7	-10.5	0.853	0.983	0.924	0.029	128
7	-10.0	0.831	1.012	0.932	0.036	128
7	-9.5	0.153	0.962	0.890	0.073	128
7	-9.0	0.612	0.768	0.690	0.037	128
7	-8.5	0.504	0.637	0.569	0.025	128
7	-8.0	0.345	0.441	0.391	0.021	128
7	-7.5	0.138	0.238	0.183	0.019	128
7	-7.0	0.007	0.057	0.026	0.012	128
7	-6.5	0.089	0.184	0.141	0.018	128
7	-6.0	0.202	0.296	0.252	0.019	128
7	-5.5	0.242	0.362	0.312	0.020	128
7	-5.0	0.294	0.397	0.338	0.019	128
7	-4.5	0.283	0.383	0.329	0.020	128
7	-4.0	0.272	0.370	0.324	0.020	128
7	-3.5	0.305	0.422	0.364	0.022	128
7	-3.0	0.328	0.450	0.395	0.023	128
7	-2.5	0.417	0.539	0.488	0.026	128
7	-2.0	0.437	0.531	0.484	0.021	128
7	-1.5	0.428	0.553	0.487	0.025	128
7	-1.0	0.410	0.542	0.478	0.027	128
7	-0.5	0.303	0.407	0.365	0.023	128
7	0.0	0.243	0.356	0.307	0.021	128
7	0.5	0.313	0.425	0.372	0.024	128
7	1.0	0.065	0.154	0.114	0.018	128
7	1.5	0.160	0.253	0.215	0.020	128
7	2.0	0.264	0.370	0.320	0.021	128
7	2.5	0.270	0.375	0.334	0.019	128
7	3.0	0.297	0.393	0.346	0.022	128
7	3.5	0.342	0.481	0.419	0.023	128
7	4.0	0.577	0.709	0.655	0.028	128
7	4.5	0.419	0.552	0.486	0.028	128
7	5.0	0.277	0.377	0.324	0.022	128
7	5.5	0.250	0.361	0.312	0.022	128
7	6.0	0.157	0.269	0.222	0.021	128
7	6.5	0.094	0.188	0.141	0.019	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
7	7.0	0.111	0.193	0.150	0.019	128
7	7.5	0.110	0.216	0.171	0.022	128
7	8.0	0.123	0.233	0.185	0.021	128
7	8.5	0.099	0.181	0.138	0.018	128
7	9.0	0.025	0.117	0.085	0.017	128
7	9.5	0.011	0.093	0.057	0.017	128
7	10.0	0.046	0.138	0.099	0.018	128
7	10.5	0.055	0.133	0.094	0.017	128
7	11.0	0.068	0.159	0.116	0.017	128
7	11.5	0.128	0.232	0.186	0.022	128
7	12.0	0.120	0.214	0.167	0.020	128
7	12.5	0.100	0.201	0.154	0.020	128
7	13.0	0.190	0.315	0.252	0.021	128
7	13.5	0.263	0.364	0.317	0.022	128
7	14.0	0.259	0.356	0.311	0.019	128
7	14.5	0.224	0.314	0.269	0.020	128
7	15.0	0.205	0.306	0.259	0.022	128
7	15.5	0.176	0.283	0.239	0.023	128
7	16.0	0.138	0.223	0.182	0.018	128
7	16.5	0.049	0.141	0.101	0.020	128
7	17.0	0.007	0.092	0.041	0.018	128
7	17.5	0.059	0.140	0.104	0.019	128
7	18.0	0.124	0.230	0.180	0.019	128
7	18.5	0.204	0.307	0.256	0.022	128
7	19.0	0.310	0.404	0.359	0.021	128
7	19.5	0.349	0.439	0.399	0.020	128
7	20.0	0.403	0.515	0.456	0.025	128
8	-20.0	0.028	0.421	0.250	0.119	128
8	-19.5	0.035	0.407	0.246	0.116	128
8	-19.0	0.064	0.374	0.229	0.088	128
8	-18.5	0.089	0.328	0.225	0.063	128
8	-18.0	0.167	0.283	0.221	0.026	128
8	-17.5	0.093	0.322	0.229	0.064	128
8	-17.0	0.011	0.426	0.254	0.121	128
8	-16.5	0.111	0.566	0.363	0.143	128
8	-16.0	0.348	0.829	0.593	0.156	128
8	-15.5	0.555	1.066	0.793	0.154	128
8	-15.0	0.919	1.413	1.144	0.153	128
8	-14.5	0.981	1.474	1.212	0.156	128
8	-14.0	0.615	1.076	0.846	0.157	128
8	-13.5	0.565	1.038	0.804	0.155	128
8	-13.0	0.470	0.943	0.705	0.152	128
8	-12.5	0.420	0.907	0.662	0.151	128
8	-12.0	0.300	0.783	0.553	0.152	128
8	-11.5	0.151	0.606	0.413	0.148	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
8	-11.0	0.028	0.469	0.286	0.135	128
8	-10.5	0.064	0.400	0.241	0.095	128
8	-10.0	0.113	0.326	0.225	0.062	128
8	-9.5	0.103	0.328	0.226	0.060	128
8	-9.0	0.108	0.339	0.237	0.068	128
8	-8.5	0.093	0.337	0.227	0.070	128
8	-8.0	0.088	0.353	0.229	0.074	128
8	-7.5	0.101	0.332	0.229	0.071	128
8	-7.0	0.084	0.346	0.228	0.084	128
8	-6.5	0.073	0.396	0.231	0.097	128
8	-6.0	0.025	0.411	0.252	0.107	128
8	-5.5	0.015	0.439	0.272	0.125	128
8	-5.0	0.011	0.423	0.255	0.115	128
8	-4.5	0.063	0.396	0.240	0.096	128
8	-4.0	0.078	0.346	0.224	0.079	128
8	-3.5	0.049	0.374	0.235	0.093	128
8	-3.0	0.007	0.456	0.264	0.139	128
8	-2.5	0.089	0.537	0.354	0.138	128
8	-2.0	0.175	0.625	0.419	0.149	128
8	-1.5	0.205	0.682	0.441	0.147	128
8	-1.0	0.264	0.728	0.510	0.151	128
8	-0.5	0.212	0.680	0.461	0.148	128
8	0.0	0.275	0.747	0.507	0.152	128
8	0.5	0.660	1.150	0.892	0.161	128
8	1.0	0.337	0.830	0.580	0.148	128
8	1.5	0.164	0.637	0.415	0.148	128
8	2.0	0.015	0.484	0.247	0.149	128
8	2.5	0.079	0.372	0.236	0.084	128
8	3.0	0.104	0.320	0.226	0.064	128
8	3.5	0.108	0.330	0.224	0.062	128
8	4.0	0.044	0.405	0.252	0.106	128
8	4.5	0.046	0.381	0.236	0.107	128
8	5.0	0.069	0.357	0.228	0.093	128
8	5.5	0.089	0.339	0.228	0.076	128
8	6.0	0.166	0.249	0.214	0.016	128
8	6.5	0.147	0.280	0.216	0.033	128
8	7.0	0.122	0.308	0.222	0.058	128
8	7.5	0.093	0.333	0.226	0.072	128
8	8.0	0.057	0.378	0.237	0.099	128
8	8.5	0.025	0.415	0.254	0.118	128
8	9.0	0.015	0.464	0.279	0.136	128
8	9.5	0.119	0.592	0.382	0.148	128
8	10.0	0.222	0.689	0.472	0.149	128
8	10.5	0.187	0.647	0.427	0.149	128
8	11.0	0.235	0.697	0.476	0.147	128

Table E1 (cont'd)

Horn	Ang(deg.)	Min.(V)	Max.(V)	Av.(V)	Std.(V)	Samples
8	11.5	0.324	0.781	0.563	0.151	128
8	12.0	0.155	0.602	0.395	0.148	128
8	12.5	0.018	0.439	0.256	0.127	128
8	13.0	0.090	0.337	0.222	0.074	128
8	13.5	0.066	0.363	0.229	0.093	128
8	14.0	0.015	0.473	0.285	0.140	128
8	14.5	0.083	0.541	0.346	0.143	128
8	15.0	0.191	0.665	0.439	0.153	128
8	15.5	0.287	0.747	0.532	0.142	128
8	16.0	0.360	0.816	0.588	0.155	128
8	16.5	0.376	0.840	0.619	0.144	128
8	17.0	0.318	0.796	0.560	0.147	128
8	17.5	0.265	0.708	0.496	0.149	128
8	18.0	0.171	0.647	0.431	0.147	128
8	18.5	0.120	0.566	0.367	0.145	128
8	19.0	0.060	0.534	0.336	0.145	128
8	19.5	0.007	0.451	0.271	0.137	128
8	20.0	0.049	0.405	0.258	0.101	128

APPENDIX F
BRIEF DESCRIPTION OF SIDELOBE CANCELLATION ALGORITHM

Sidelobe Cancellation Algorithm

The narrow band version of the sidelobe cancellation algorithm employed in the program MYSLC is developed briefly as follows:

Consider the schematic shown in Figure F1 where the signals from the main-beam and sidelobe canceller arrays are combined as shown. The signals from each of the sidelobe canceller receiver elements are combined in the beamformer network to give the beamformed output. For the single jammer case, the maximum of the beamformed output should correspond to the jammer direction. For example, the beamforming network in this case corresponds to a simple 2048 point spatial FFT using 8 inputs from the receiver array and the rest zero filled. The residual signal, r(t), obtained by subtracting the weighted beamformed output from the main-beam signal, y(t), is given by:

$$r(t) = y(t) - w \cdot \mathcal{F}_m$$

where

$r(t)$ = residual signal
$y(t)$ = main-beam signal
w = complex weight factor
$\mathcal{F}_m$ = maximum beamformed (spatial FFT) output
t = time

The average residual power P_r is therefore given by:

$$
\begin{aligned}
P_r &= E[r^{*} \cdot r] \\
&= E[\,|y(t)|^2 - (w \cdot \mathcal{F}_m)^{*} \cdot y(t) - y^{*}(t) \cdot (w \cdot \mathcal{F}_m) + |(w \cdot \mathcal{F}_m)|^2] \\
&= E[\,|y(t)|^2] - w^{*} \cdot E[\mathcal{F}_m^{*} \cdot y(t)] - w \cdot E[y^{*}(t) \cdot \mathcal{F}_m] + |w|^2 \cdot E[\,|\mathcal{F}_m|^2] \\
&= P_{mb} - w^{*} \cdot E[\mathcal{F}_m^{*} y(t)] - w \cdot E[y^{*}(t) \cdot \mathcal{F}_m] + |w|^2 \cdot E[\,|\mathcal{F}_m|^2]
\end{aligned}
$$

where E[] represents the expectation operator and P_{mb} is the main-beam power.

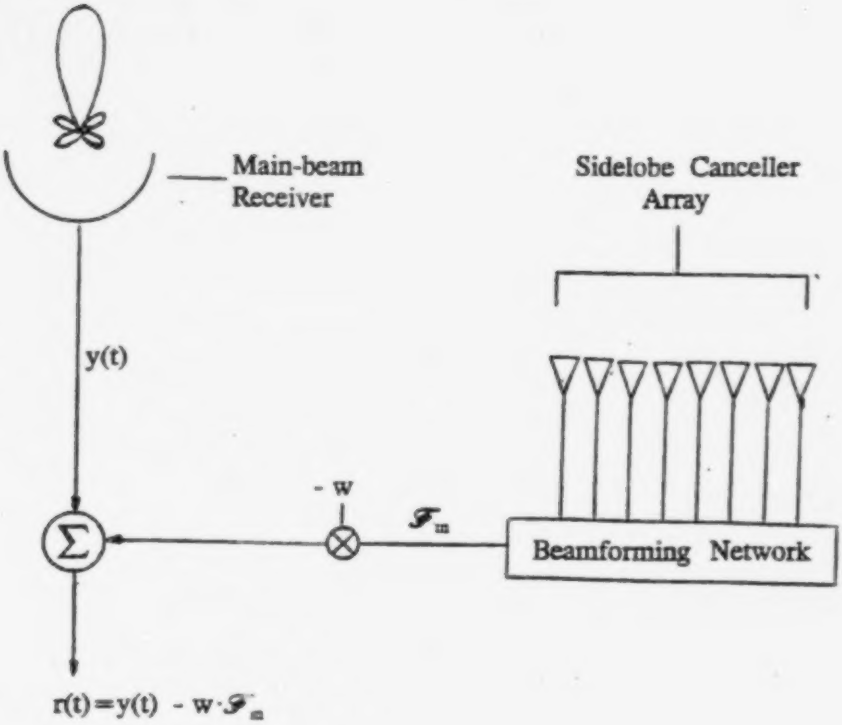

Main-beam
Receiver
Sidelobe Canceller
Array
y(t)
- w
$\mathscr{F}_m$
Beamforming Network
$r(t)=y(t) - w \cdot \mathscr{F}_m$

Figure F1 Schematic diagram of sidelobe canceller receiver arrangement

To reduce the effect of a jammer signal entering a sidelobe of the main-beam receiver, the residual power in the direction of the jammer must be minimized. This is done by finding the value of w that minimizes P_r, i.e.:

$$\partial P_r / \partial w = - E[y^*(t) \cdot \mathcal{F}_m)] + w^* \cdot E[\,|\mathcal{F}_m|^2] = 0$$

leads to:

$$w^* = E[y^*(t) \cdot \mathcal{F}_m)]/E[\,|\mathcal{F}_m|^2]$$

$$w = E[y(t) \cdot \mathcal{F}^*)]/E[\,|\mathcal{F}_m|^2]$$

The above weights must be estimated when just the jammer signal is present i.e. when the return signal from the main-beam antenna is not coming from the range cell of the target (source) being jammed.
Since the main-beam antenna of the Area 5 Experimental Array Radar System (EARS) consisted of an 8 element vertical array, the instantaneous, total main-beam output signal after jammer cancellation was calculated according to:

$$P_T(t) = \sum_{n=1}^{n=8} (r_n^*(t) \cdot r_n(t))$$

APPENDIX G
MONTHLY REPORTS

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES

Contract Serial W7714-2-9607
November 30, 1992

PROJECT STATUS

1.0 Schedule

The contract is currently on schedule.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

No outstanding areas of concern have yet developed at this early point in the contract.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) As mentioned in the monthly report for October, a significant amount of literature was provided by the Scientific Authority which had to be read, on such topics as the jamming scenarios to be used, jammer dispersion analysis, and analysis of the effects of noise level and array gains on the performance of a sidelobe canceller array. Also, the Scientific Authority had created a preliminary software package for studying side lobe cancellation with which we had to become familiar. At this point, most of the background material has been reviewed and the software package has been studied extensively. The familiarity gained with the software has made it possible to make modifications with confidence, and to begin carrying out some simulations. In the process of studying the software, a couple of small errors were identified in the software which have since been corrected.

1.2 A. Wilkinson

i) A MATLAB subroutine was created to calculate the zeros of a first order Bessel function. A table of the results was used for generating the Taylor weighting for a circular taper. A weight was generated for each element in the array. It was necessary to calculate the distance from the centre of the array for each element and then calculate its weight. Two ASCII files were created, one for the weights of the left-hand and right-hand side of the array respectively. These files were used as inputs to GENXDATA and applied to the data to produce better results than the results with no taper.

ii) Using the new version of MATLAB (4.0), a surface plot of the Taylor tapering was created.

iii) GENXDATA was run several times under various conditions. The results were plotted to determine if they agreed with the conditions supplied. After some debugging, all conditions were checked and appear to be correct.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES

Contract Serial W7714-2-9607

December 31, 1992

PROJECT STATUS

1.0 Schedule

The contract is currently on schedule.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

No outstanding areas of concern have been encountered to date.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) Continued simulation studies of the effects of jammer dispersion, noise level and array gains on the performance of a sidelobe canceller array using the software package mentioned in previous reports. The analysis makes use of the frequency dispersion studies done on the main beam and sidelobe canceller systems at Area 5 carried out by Applied Silicon Inc. Canada. Some of this dispersion data was also plotted out and saved for future reference.

iii) Began process of becoming more familiar with some software previously created by the Scientific Authority (i.e. HSDLREAD.FOR) for reading the data logger tapes. This software will have to be modified to read the data produced by the sidelobe cancellation experiments to be carried out at Area 5.

1.2 A. Wilkinson

i) Debugging of GENXDATA continued into the first week of December. Minor changes were made to the shape of the array to make it more symmetrical with the centre positioned at a height of 20 meters. The various adjustments to the angles are still being analyzed to determine which produce the best results.

ii) A MATLAB subroutine was modified to create the aperture distribution of a typical Bayliss aperture illumination pattern. The amplitude of the aperture distribution was plotted and produced results consistent with those shown in the reference material (see: 'Array Pattern Control and Synthesis',Proceedings of the IEEE, Vol. 80, No.1, January 1992, pg. 141-151). The Bayliss aperture weighting for the monopulse difference signal will be combined with a linear Taylor aperture weighting for the sum signal as the taper values used in GENXDATA.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES
Contract Serial W7714-2-9607
January 31, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well, and is presently on schedule. Most of task 2, 'Monopulse Sensitivity to Array Tilt Analysis', has been completed by Ms. Wilkinson and she has started doing some work related to task 1. Mr. Brookes is on schedule with task 1 and has done some work related to task 3 concerning trials support (i.e. creation of software for reading and processing data logged by the new experimental sidelobe canceller array at Area 5).

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) In the December report it was noted that the HSDLRD.FOR software (previously used for reading data logged from the ELAT system) would have to be modified to read the new data format from the output of the experimental sidelobe canceller (slc) array. After an extensive examination of the old software it has since been determined that significant changes in the data logger format required a major software rewrite. A data file was obtained from a test run of the slc array data logger to be used as a guide for creating the new software for reading the data. This file was used to determine the kinds of error handling required by the program and to determine if there might be any previously undetected hardware problems. Most of the month was spent simultaneously studying the data file and creating the new software since it turned out to require a significant amount of error handling ability. The software is nearly completed and a slightly modified
version will soon be ready for use on a PC to examine data on location during upcoming experimental trials of the new system at Area 5.

iii) A small amount of time was spent helping the Scientific Authority to debug some of the monopulse simulation software.

1.2 A. Wilkinson

i) Two MATLAB subroutines were completed during January; the first to create the aperture distribution of a typical Bayliss pattern and the second of a linear Taylor pattern. A set of weights was calculated for each pattern. There is a different Taylor weighting for each row of the array (i.e. 64 weights calculated using the positions of the elements of column 1 on the left-hand side). It was determined that these 64 weights were sufficient even though there are small offsets on every second column. Thirty-two Bayliss weights were calculated; one for each column of the right-hand side of the array. The weights for the left-hand side are identical.

In GENXDATA, the linear Taylor aperture is combined with the Bayliss aperture and used as the taper values. First the Taylor weights are applied to each element of each column and then the Bayliss weights are applied to the sums of each column (i.e. after being multiplied by the Taylor weights). Several runs of GENXDATA were made; however, the results obtained are still being studied.

ii) Two days were spent creating hardcopy plots of Lake Huron data for Ross Turner. This was done using the GRAFTOOL software package.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES

Contract Serial W7714-2-9607
February 28, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well and on schedule. Ms. Wilkinson is continuing with work related to task 1 and Mr. Brookes is continuing his own work on task 1 as well as helping with ongoing trials at Area 5 (i.e. task 3).

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) The software for reading the files from the data logger has been completed and tested for use on the VAX. A slightly modified version has also been created for use on an IBM compatible PC using
NDP Fortran 77 with the '-vms' switch activated during assembly.
The new program is called SLCRD.FOR.

iii) Approximately 6 days were spent in support of experimental trials at Area 5. A significant portion of this time was spent in
trouble shooting malfunctioning equipment. After finally getting the radar itself working, and collecting several data files from the sidelobe canceller array, it was discovered that the SLC data was not being recorded properly by the data logger. A series of diagnostics tests were conducted to track down the cause of the malfunction. New software had to be created to read the data files resulting from these tests. The two main programs used to test the data pathways, TWOWAY and CITST1, had been created on previous contracts for testing the former ELAT system, but were still useful for similar tests on the new system. To run the data transfer tests, the System Controller software (EDWIN) was set in 'backup' mode and tracking was initiated. Next, TWOWAY was run on the Slow Speed Tracker Processor (SSTP) computer with the first option from the menu selected, to send a block containing a prearranged counting pattern from the SSTP through PIU1 (Processor Interface Unit #1) and the BCU (Bus Control Unit) to the consumer interfaces for the array processor and the data logger respectively. If the data was being transferred correctly from the SSTP to the consumer interface for the array processor, then, using CITST1, the proper counting pattern would appear on the terminal connected to the scientific computer. The identical counting pattern should also have been transferred to the consumer interface of the data logger and recorded in a data file using HSDL. After analysing the recordings from the data logger, it was determined that a chip in the consumer interface for the data logger had become defective and needed replacement. Once this had been accomplished, the data collection hardware

and software worked as required. This was confirmed by examination of data files recorded while using TWOWAY, and SLC2. The program SLC2, is normally used for recording the signals coming from the off target range cells as well as at the target range cell; however, since the radar transmitter/receiver was turned off for this test all signals were near zero volts.

1.2 A. Wilkinson

i) After the results of the January version of GENXDATA were reviewed, additional modifications to the adjustment equations were necessary. These changes produced smaller and more consistent errors. The Taylor/Bayliss taper values (i.e. azimuth monopulse) were added to the new version of GENXDATA.

Many runs of GENXDATA were made in an attempt to find a scenario that produced unexpected results. The following cases were examined:

Frequencies: 8.5, 9.0, 9.5, 10.0, 10.5 GHz
Targets Heights: 5, 10, 20 meters
Angles off Boresight: 0, 5, 10, 15 degrees
Side tilt: 25 degrees
Tilt Back: 20 degrees
With and Without Tapering

The Scientific Authority requested several of the results in the form of hardcopy plots.

The output errors for each frequency at each range were averaged to produce the average error at each range. Plots of these results were also given to the Scientific Authority for review.

ii) The Scientific Authority requested some hardcopy plots of the Lake Huron data in both report and view graph format. This was done using the GRAFTOOL software package.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER MEASURE STUDIES
Contract Serial W7714-2-9607
March 31, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well and on schedule. Ms. Wilkinson is continuing with work related to task 1 and Mr. Brookes is continuing his own work on task 1 as well as helping with ongoing trials at Area 5 (i.e. task 3).

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) Several days were spent in support of experimental trials at Area 5 testing the experimental system, some software and to collect experimental data. Three days, March 3,4,and 8, were entirely devoted to collecting experimental data to be used in testing various tracking algorithms such as side lobe cancellation of jamming signals.

For the trials on March 3, a fairly stable, but unidentified reflector at about 14 km was used as the main target (instead of a corner reflector), and a beacon jammer was positioned about .1.5 km away at an azimuth angle of between 10 and 15 degrees from the antenna boresight. Thirteen data files were collected using both the SLC1 and SLC2 programs (created by E. Riseborough) with the beacon jammer on and then off for comparison. Data was also collected for different receiver attenuation settings.

Two kinds of trials were undertaken on March 4. In the morning, and early afternoon, eight data files were obtained using a corner reflector as the main target with a beacon jammer just off the boresight turned on then off. Later in the afternoon, the corner reflector was effectively replaced by a helicopter as the main target, hovering at several different altitudes at the same range as the corner reflector.

On March 8, several more trials were done using the corner reflector and a snowmobile as targets with a beacon jammer located off boresight by several degrees.

iii) Most of the remaining part of the month of March was spent editing, reformatting and doing some analysis of the data obtained during the earlier experimental trials. The editing, reformatting and backing up of the experimental data is ongoing, but should be completed in the first few days of April.

iv) Assisted Ms Wilkinson in debugging some of her RML software.

1.2 A. Wilkinson

i) The azimuth monopulse version of GENXDATA was verified by running many scenarios, giving consistent results for each. The following scenarios were examined:

No. of Frequencies: 5
Targets Heights: 5, 10, 20 meters
Angles off Boresight: 0, 5, 10, 15, 45 degrees
Side tilt: 25 degrees
Tilt Back: 20 degrees
With and Without Tapering

To smooth out and reduce the monopulse angle estimation error associated with multipath interference, an average error over several frequencies was produced for each range. This simple averaging had an inherent problem in that signals with low amplitude (tending to give larger errors) were given equal weight to higher amplitude signals. To reduce this effect the angle estimation error for each frequency and range was weighted by the signal amplitude for that frequency and normalized to the sum of the signal amplitudes of all the frequencies.

ii) GENXDATA was modified to calculate the elevation monopulse errors. This involves summing the top and the bottom halves of the array, as apposed to the azimuth monopulse which requires the left and the right sides to be summed. Once again Taylor and Bayliss tapering was used. Matlab routines were written to calculate the weights. Bayliss weights for a complete 64 element column were generated and the taper was cut off for the shorter columns. The Taylor taper was then applied to the sum of the columns.

The scenarios described above for the azimuth monopulse were repeated for the elevation monopulse. As expected, the resulting errors were much larger and the effect of the tapering was minimal. Side tilt had no effect on elevation monopulse and was therefore set to zero for all tests.

Several figures, for inclusion in a DREO working paper written by the Scientific Authority, were produced.

iii) The data created by GENXDATA is currently being run through the RML algorithm. The data was first reformatted as required by RML and the necessary changes to the algorithm were made. Some of the data was run through and the results are very good (i.e. RML is estimating the exact target height).

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES
Contract Serial W7714-2-9607
April 30, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well and on schedule. Ms. Wilkinson is continuing with work related to task 1 and has begun some work under task 3 related to radar trials support. The analysis of the Rotman lens data is related to both of these tasks since it is experimental data that is related to the development of the experimental array system. Mr. Brookes is continuing his own work on task 1, pre-processing and reformatting the experimental SLC data from the EARS (Experimental Array Radar System) at Area 5 and analysing the data.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) The data collected from the SLC experiments at Area 5 has all been preprocessed to remove as many errors as possible, then reformatted and backed up onto Archive tapes for future reference. The output from each data logger file consisted of 6 new files of:
a) high frequency, on-target data, b) high frequency, off-target data, c)low frequency, on-target data, d) low frequency, off-target data, e) a range data file giving each on-target, and off-target range cell reading and the block number of the reading, and f) a data file containing a record of locations of many of the errors in the original data logger file.

iii) Some time was spent developing a more detailed outline of how the experimental data will be analysed. The following items are being considered in the data analysis:

a) obtain phase and amplitude plots of the experimental data; it may be necessary to limit this to only a representative sampling of the data since so many files are involved that this could entail a significant amount of time by itself.

b) do tracking analysis of the experimental data obtained with the helicopter. Since the data was taken at only one frequency, this type of analysis is limited to using the monopulse algorithm or using other algorithms such as CHA with sub-arrays used in place of frequency agility.

c) Do a preliminary analysis of the noise covariance matrix associated with the SLC array to make sure that the off diagonal elements are essentially zero. This implies that the noise in each element of the SLC array is uncorrelated (and preferably of equal strength). If the noise between each channel of the SLC array is correlated, this will have to be corrected.

d) Investigate the need for correcting the data from main-beam and sidelobe canceller arrays for possible gain and phase errors.

e) Investigate what modifications have to be made to the present SLC simulator software to be able to process the new experimental data.

At present, work is continuing with items c) and e) and more items may be added to the above list as the analysis progresses.

iv) Began a cursory investigation of creating software for simulating main-beam jammer cancellation algorithms. An algorithm has been presented by the Scientific Authority for examination.

1.2 A. Wilkinson

i) Some elevation monopulse data (i.e. the sums of the top and bottom halves of the array), created by GENXDATA was tested using the RML tracking algorithm. Five frequencies were used in RML and in generating the simulated data. The data was first reformatted as required by RML and the necessary changes to the algorithms were made. The results obtained using RML to track a simulated target with the array pointing straight ahead (i.e. no side tilt, no tilt back, no angle off boresight, and no beam steering) were very good, with the correct target height being estimated. However, when one of the adjustments (an array tilt for example) was applied to the data the RML gave poor estimates. This work has been put on hold until a later date.

ii) For the azimuth and elevation monopulse data, generated by GENXDATA, the RMS values for the monopulse angle estimation errors due to multipath were calculated for various scenarios specified by the Scientific Authority. The scenarios, for each of the 5,10, and 20 metre target heights, included: a) 10 GHz with tapering, b) 10 GHz without tapering, c) averaging over the five frequencies , and d) normalization over the five frequencies. The results were presented in table format.

To date, all the data generated by GENXDATA has been for sea-state 3. The scenarios, as described in the March 1993 monthly report, were repeated for sea-state 2. Also, the RMS errors, as described above, were calculated for sea-state 2. As expected, the errors produced by SS2 were larger than SS3. Several figures were created from the results from SS2, for inclusion in a DREO working paper written by the Scientific Authority.

iii) Analysis of the Rotman lens data was started. For the S21 parameter, the amplitude, in dB, was calculated from the magnitude. The amplitudes of all of the nine ports versus the frequency (in GHz) were plotted on one plot. This work is being done in MATLAB, therefore some time is being spent investigating some of the features of MATLAB that have not yet been used (eg. legends, curve symbols, and sizes, line styles etc.).

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES

Contract Serial W7714-2-9607
May 31, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well and on schedule. Ms. Wilkinson is continuing with work related to task 1c) -analysis of Area 5 experimental data and phased array simulator and, task 3) -analysis of Rotman lens data for trials support. The analysis of the

Rotman lens data is related to both of these tasks since it is experimental data that is related the development of the experimental array system. Mr. Brookes is continuing his own work on task 1c) analysis of data from the EARS (Experimental Array Radar System) trials during the spring at Area 5.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) As mentioned in the previous report for April, the data collected from the SLC experiments at Area 5 has all been preprocessed to remove as many errors as possible then reformatted and backed up onto archive tapes for future reference. The month of May was spent analysing this data to determine its quality, identify any apparent irregularities and to suggest or carry out possible methods of improving the data quality. For each of the experiments carried out at Area 5, a series of FFT plots is being produced for successive snapshots usually 128 or 256 samples in length. Special software had to be written to create the plots; due to the number of experiments, and their length, the software had to produce as many plots (9) on the same page as possible. So far, plots for all of the March 8 experiments and some of the March 4 runs have been produced. A cursory examination of the results indicated that the side-lobe canceller array data had significant I-Q phase and/or amplitude imbalances. There was also evidence of 120 Hz interference on some the runs as well, and there was also evidence that some data spikes had slipped through the data pre-processing stage.

1.2 A. Wilkinson

i) To date, the normalized monopulse angle estimation errors, from the results of GENXDATA using five frequencies, have been minimized by weighting the individual errors by the signal amplitudes. It has been determined that a further reduction in the errors can be obtained by weighting with respect to the squares of the amplitudes. This produced significantly smaller errors. New results were obtained with this method for the various scenarios described in the two previous reports, and new plots were produced for the Scientific Authority.

ii) Analysis of the Rotman lens data continued this month. For the S21 parameter, the phase angle, was calculated using the difference with respect to the out 4 channel. For the centre port, the out 4 and 5 channels were normalized to the out 3 channel. When the phase angles were plotted, there were several discontinuous jumps in the phase output. This occurred when the signal vector passed from the second to the third quadrant (i.e. from $\pi/2 \langle \theta \leq \pi$ to $-\pi \langle \theta \langle -\pi/2)$. To obtain a continuous plot of the phase, 2π radians (or 360°) was added to all the negative phase angles. The phase angles of all of the nine ports versus the frequency (in GHz) were plotted on one plot.

iii) On March 4, 1993, helicopter trials were conducted at Area 5. Raw main beam data, as well as SLC data, were collected. This data was corrected and reformatted by Mr. Dan Brookes and stored on archive tapes. As part of the data analysis of the reformatted data, the total power was calculated and plotted against the sample number for each of the files taken that day. The total power was calculated by summing the power from all eight receiver arrays for the main-beam and side-lobe arrays separately; i.e. the total power P_t in dB was given by:

$$P_t = 10 \log_{10}\left(\Sigma_{i=1}^{i=8} (I_i^2 + Q_i^2) \right)$$

where: I_i = In-phase signal for receiver i
Q_i = Quadrature signal for receiver

Since the data was reformatted on the VAX, it could not be read on the PC and therefore the processing of the power had to be done on the VAX as well. Thirty-eight runs were produced on March 4. Each run collected data for each of the following:

(a) High and low frequencies
(b) On and off target
(c) Raw main beam and SLC data

A large portion of this work on the helicopter runs has been done and the remainder will continue into June.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES

Contract Serial W7714-2-9607

June 30, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well and on schedule. Ms. Wilkinson is continuing with work related to task 1c) -analysis of Area 5 experimental data and phased array simulator and, Mr. Brookes is continuing his own work on task 1c)- analysis of data from the EARS (Experimental Array Radar System) trials during the spring at Area 5, and work on task 1d)- the effect of multi-path interference on side-lobe cancellation methods.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) Created and tested two new programs for doing initial side-lobe cancellation studies of March trials data from Area 5. The programs called MYSLC.FOR and MYSLCPC.FOR are similar in the processing they do except that the first uses the FPS5200 array processor to carry out the necessary fft's while the second uses an fft subroutine written in fortran 77. Both programs were designed to carry out side-lobe cancellation in the same way as the original software simulator created by the Scientific Authority (E. Risborough) but the code has been greatly simplified for ease of use in analysing the data. The programs have been tested on simulated data to verify that they work, and are presently being used to analyse the experimental data. The initial results appear promising; in one instance the side-lobe cancelation technique gave a 10-15 dB improvement in the signal to noise ratio. This analysis will continue into next month.

In parallel with this analysis, studies are also being conducted into the effect of multi-path interference. The software has been created for simulating this kind of data for a narrow band jammer and will be analysed using the above slc software programs. This work will also carry on into July. The effects of a wide band jammer will be carried out later.

1.2 A. Wilkinson

i) Continued analysis of the data collected at Area 5 during March 1993. As discussed in the previous report, the total power was calculated for both the slc and main beam arrays and plotted against the sample number for the thirty-eight runs from March 4. Each run collected data for the following:

(a) High and low frequencies
(b) On and off target
(c) Raw main beam and SLC data

Hardcopy power plots were produced and studied; the files that appeared to have the greatest power on average were selected to study the amplitude and phase characteristics for the receiver arrays. Since all of the horns of the main beam receiver array appeared to have very similar amplitude responses, horn 4 was chosen as a typical example from which to obtain a representative set of plots for the amplitude (in volts) and the phase (in radians) as a function of the sample number.

While working on the amplitude and phase plots for the March 3 data, power plots were also generated for the data obtained on March 8, 1993. For this data a corner reflector mounted on a tower was used as the target instead of the helicopter. Power plots for all the high frequency runs were produced. Further analysis of this data will continue into next month.

ii) The effect of adding noise to the azimuth and elevation monopulse was studied. A noise sample of Gaussian distribution (by summing 12 uniform variates) was calculated for each element and added into the simulation. Several scenarios were studied.

- No. of frequencies (5) for various SNRs
- target heights of 2.5, 5, 20 meters
- SS3 for azimuth monopulse and SS2 for elevation monopulse
- constant SNR for the entire run
- (1/R**4) normalization for the entire run

Error plots were provided to the Scientific Authority for analysis.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES
Contract Serial W7714-2-9607
July 30, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well and on schedule. Ms. Wilkinson is continuing with work related to task 1c) -analysis of Area 5 experimental data and phased array simulator and, Mr. Brookes is continuing his own work on task 1c)- analysis of data from the EARS (Experimental Array Radar System) trials during the spring at Area 5, and work on task 1d)- the effect of multi-path interference on side-lobe cancellation methods.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) As noted in the previous monthly report, a program called MYSLC was created to do initial side-lobe cancellation studies of March trials data from Area 5. The programs were tested and verified on simulated data, and are presently being used to analyse the experimental data. The processing of the data from March 4 is nearly complete and some of the data from March 8 has also been studied. Plots of the results obtained thus far have been submitted to the Scientific Authority for evaluation.

In the previous report it was mentioned that studies were also being conducted into the effect of multi-path interference on side-lobe cancellation. Due to time constraints for the month of July (i.e. not the entire month was spent on this contract), and due to hardware problems with the VAX (it was continually 'crashing') during several days toward the end of the month, this analysis was delayed until August.

1.2 A. Wilkinson

i) Assisted in the preprocessing and analysis of data from the radar trials of March 8, 1993. This involved correcting and reformatting some of the data files using a program called SLCRD1, created by D. Brookes. Occasionally the program required modifications to correct for new errors found in the data and specifically pinpointed by examining a 'dump' of the file, in HEX. format, at the block identified by error check software in SLCRD1. After making the necessary modifications the program was rerun to produce the corrected and reformatted data.

For the reformatted data, the total power was calculated and plotted against the sample number. As well, for horn 4 from these files, the amplitude (in volts) and the phase (in radians) were calculated and plotted as functions of the sample number. Runs 3 to 12 were analyzed. Each run collected data for each of the following:

(a) High and low frequencies
(b) On and off target
(c) Raw main beam and SLC data

The cancelled total power for the above runs was calculated using MYSLC and stored in data files for further analysis by Mr. Brookes.

ii) Several plots showing the results of azimuth and elevation monopulse (with no noise) were requested by the Scientific Authority for inclusion in a DREO working paper.

iii) The effect of adding noise to the azimuth and elevation monopulse was described in the June 1993 monthly report. For all of the scenarios studied last month, the RMS errors were calculated and provided in table format to the Scientific Authority.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES
Contract Serial W7714-2-9607
August 31, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well. Ms. Wilkinson went on leave during the month of August but will resume her work the beginning of September. Mr. Brookes is continuing his work on task 1c)- analysis of data from the EARS (Experimental Array Radar System) trials during the spring at Area 5, work on task 1d)- the effect of multi-path interference on side-lobe cancellation methods and work on task 3- Radar Trial Support.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

There are no significant areas of concern at this time.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) Work was continued into studies of the effects of multi-path interference on side-lobe cancellation.

iii) Was required to create and verify graphics software for testing the Rotman lens attachment to the SLC array. The software, written for the Matrox QG-640 colour graphics board and monitor, was used for on site examination of the antenna patterns of the (Rotman lens)-(SLC array) combination. The data for the antenna patterns was read from files consisting of 128 samples of In-phase and Quadrature signals for each antenna element of the array, at each of 81 angular positions (-20 to 20 degrees in 0.5 degree increments) of a stationary beacon relative to the array.

Two similar programs were created to plot the antenna patterns on a colour monitor. The program called ROTMAN was created to plot the signal amplitude for all 8 elements simultaneously, as a function of angle, whereas ROTMN1 was used for plotting out the antenna patterns of each individual antenna element. The above (Fortran IV) programs had to be linked to some previously developed graphics software (i.e. DRAWPT and QGDRF4) in the following manner:

```
LINK ROTM**,DRAWPT.OBO,QGDRF4,SYLB4
```

and the programs make use of the graphics setup file called "rotmnvs.ang".

iv) Began conducting antenna pattern tests of the (Rotman lens)-(SLC array) combination using the software described in **iii)** and to do jamming experiments with this setup as well. These experiments and the subsequent analysis of the data will continue into next month.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER MEASURE STUDIES
Contract Serial W7714-2-9607
September 30, 1993

PROJECT STATUS

1.0 Schedule

The work is progressing well. Ms. Wilkinson returned from leave during the month of August and resumed work at the beginning of September. She is currently assisting Mr Brookes with ongoing work on task 1c), as well as task 2. Mr. Brookes is continuing his work on task 1c)- analysis of data from the EARS (Experimental Array Radar System) trials during the spring and late summer at Area 5, work on task 1d)- the effect of multi-path interference on side-lobe cancellation methods and work on task 3- Radar Trial Support. Mr Brookes is also involved with creating main-beam jammer cancellation software for analysis of some of the data obtained during the March trials; also part of task 1c). For the most part, the work is continuing on schedule with only one concern to be discussed below in section 3.0.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

One small area of concern exists with respect to the main-beam cancellation software being developed for the Scientific Authority. Since the algorithm was received somewhat late in the contract, and since the level of effort required for ongoing data analysis was slightly more than originally scheduled, this part of the contract may not be totally finished by the completion date. The Scientific Authority is fully aware of this condition and supports the reasons. We will however still strive to finish this work by the completion date.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) Work was continued into studies of the effects of multi-path interference on side-lobe cancellation.

iii) Continued participation in experimental trials with the Rotman lens attachment to the EARS system that was started in late August, 1993. The purpose of these trials were to determine the beam patterns of the Rotman lens and to test the ability of the Rotman lens to facilitate side-lobe cancellation of a beacon jammer. Data was collected on three separate days, Sept. 2, 3 and 7, 1993, using a corner reflector mounted on a raft, located at various positions on the Ottawa river, as the main target, and a beacon jammer located on the shore at the 'White Trailer'. A more detailed account of these trials has been produced for the Scientific Authority by personnel of Applied Silicon, the company responsible for trial systems support.

iv) Analysis of the data collected during late August and early September is ongoing. During September, the Rotman lens beam pattern analysis was completed and colour plots of the data were produced for the Scientific Authority, and for inclusion into the contract final report. These plots indicate that the Rotman lens was doing essentially what it was designed to do, which was very promising. The correction and reformatting of the side-lobe jamming data collected during September is being carried out by Ms Wilkinson and the reformatted data is being analysed by Mr. Brookes.

v) Work was started on creating a main-lobe jammer cancellation simulator, based on the basic algorithm provided by the Scientific Authority, using a fairly detailed model of the actual main beam array used on the EARS system. The objective is to use this simulator software to analyse actual experimental data obtained during trials in March 1993. During these trials a military helicopter was used as the target and hovered at various altitudes over a beacon jammer located on a raft (in the main beam of receiver) on the Ottawa River near the Area 5 test site. So far, the majority of the time spent on this task was involved in modelling the individual beam patterns of each array element based on their measured dimensions. One model which agrees

well with the near field beam patterns of the array elements as measured by STC (the builders of the array) assumes that the horn acts like an E-plane sectoral horn with the E field oriented horizontally. To get the required beam pattern the horns are actually operated in pairs
(ie. 8 pairs along the array).

1.2 A. Wilkinson

i) Several figures were reproduced for inclusion in a paper to be presented by the Scientific Authority in October 1993. The figures were created with GRAFTOOL and then exported to Postscript in order to be included into the paper written in Word Perfect. Transparencies were also produced.

ii) In September 1993, more experimental trials were conducted at Area 5. The objectives of these trials was to test the Rotman lens attachment to the SLC array for side-lobe cancellation of a beacon jammer. The Data was collected in virtually the same format as described in previous reports for the March 1993 trials with one minor exception. In the intervening time between the two sets of trials, Applied Silicon personnel made some modifications to the radar system and the data logger so that some of the data flags were changed slightly. The flags that previously indicated the last record of main-beam data and the beginning of the SLC data, ie the hexadecimal words 'f0fe' and 'f1fe' respectively, were changed to 'f0fd' and 'f1fd' respectively. In order to analyze this data it first has to be corrected and reformatted, therefore slight modifications were made to the previous software (SLCRD1) used to accomplish this objective. correcting the data requires running Mr. Dan Brookes's program called SLCRD1 with one small correction. The March data uses 'f0fe' and 'f1fe' as flags and the September data uses 'f0fd' and 'f1fd'. The analysis of the September trials data will continue into October.

MULTI FUNCTION RADAR
ELECTRONIC COUNTER COUNTER
MEASURE STUDIES
Contract Serial W7714-2-9607
October 31, 1993

PROJECT STATUS

1.0 Schedule

The work on the contract was being finished off during this month. Ms. Wilkinson continued to assist Mr Brookes with ongoing work on task 1c), analysis of the data taken from the EARS during late summer, as well as task 2. Mr. Brookes also continued with some work on task 1c) until the end of the contract. The majority of the month, Mr. Brookes spent writing the contract final report. For the most part, the work was on schedule with only one concern that was discussed in last months report.

2.0 Budget

The contract is currently on budget

3.0 Areas of Concern

As mentioned in the previous report, there was some difficulty completing the simulation software of the main-beam cancellation algorithm submitted by the Scientific Authority, before the expiration date of the contract. The Scientific Authority was fully aware of the difficulty and supported the reasons.

PROJECT PROGRESS

1.0 WORK DONE

1.1 E. D. Brookes

i) Technical leadership of AIT DREO team.

ii) Most of the month of October was spent writing up the final report, which has been submitted to the Scientific Authority for approval.

iii) Assisted Ms. Wilkinson with some of the data analysis for the August-September trials.

iv) As stipulated in the September report, work was started on creating a main-lobe jammer cancellation simulator. The simulator was to be based on the basic algorithm provided by the Scientific Authority using a fairly detailed model of the actual main-beam array used on the EARS system. The majority of the time spent on this task was involved in modelling the individual beam patterns of each array element of the main-beam array based on their measured dimensions. The model which agreed the best with the near field elevation beam patterns of the array elements, as measured by STC, assumed that the horns act like E-plane sectoral horns with the E field oriented horizontally. To get the required beam pattern the horns were operated in pairs (ie. 8 pairs along the array). The horizontal beam patterns of each horn were also included in the simulation software as well as the effect of multipath interference. The Fortran 77 subroutine used to simulate the azimuthal and elevation beam patterns of the 8 elements of the main-beam array was named BEAMPAT1.FOR. A similar subroutine, named BEAMPAT2.FOR was created to model the elevation and azimuthal beam patterns of the 8 element horizontal sidelobe canceller (SLC) array. The SLC array consisted of 8 standard gain Narda-640 pyramidal horn receivers and the model used their actual physical dimensions for the simulation. The last major step in simulating the receivers for the Area 5 system was to include the effects of the parabolic reflector used to compress the azimuthal beam pattern of the main-beam array. This was fairly complex, and although it had been started, it could not be completed by the end of the contract. The results of the modelling that had been completed by the expiry date, were presented to the Scientific Authority.

These subroutines were included in the sidelobe cancellation simulation software to do sensitivity tests of the algorithm under realistic conditions. The results of some of these tests are included in the final report.

1.2 A. Wilkinson

i) The Scientific Authority identified a problem with some of the earlier analysis of the MARS data obtained from the Lake Huron trials. This required that some of the results obtained using RMONO and phase monopulse had to be redone and new plots of the results produced for inclusion into a DREO report.

ii) The analysis of the September trials data continued into October. Most of this involved the preprocessing and reformatting of the data using the program SLCRD2.

iii) Signal to noise ratio (SNR) studies of the GENXDATA simulator were started in October. These initial studies were done for various SNRs for a specified frequency, target height of 20 m, and the same side-tilt, back-tilt and angles off boresight as used in previous studies of the simulator.

APPENDIX H
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APPENDIX I
LIST OF FIGURES

List of Figures

Figure 1.1 The Low Angle Tracking Problem

Figure 2.1 AIT Organization Chart

Figure 3.1 Scale drawing of vertical main-beam array

Figure 3.2 Schematic diagram of receiver system used in simulations

Figure 3.3 Pyramidal horn geometry and coordinate system

Figure 3.4 Horn pair geometry in multipath environment

Figure 3.5 Comparison between theoretical and measured amplitude and phase patterns assuming pyramidal horn geometry at 9.6 GHz

Figure 3.6 Comparison between theoretical and measured amplitude and phase patterns assuming pyramidal horn geometry at 8.6 GHz

Figure 3.7 Comparison between theoretical and measured amplitude and phase patterns for sectoral horn geometry at 9.6 GHz

Figure 3.8 Comparison between theoretical and measured amplitude and phase patterns for sectoral horn geometry at 8.6 GHz

Figure 3.9 Azimuthal beam pattern for geometry used in simulations

Figure 3.10 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 10 m above the reflecting surface.

Figure 3.11 Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 20 m above the reflecting surface.

Figure 3.12	Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 30 m above the reflecting surface.
Figure 3.13	Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 40 m above the reflecting surface.
Figure 3.14	Effect of multipath on elevation beam patterns of the simulated 8 element vertical array at 50 m above the reflecting surface.
Figure 3.15	Theoretical azimuthal beam patterns for the simulated 8 element horizontal array showing the effect of multipath, assuming a significant wave height of 1.0 m
Figure 3.16	Plots (a) to (d) show the improvement in the effective output to noise ratio for different noise levels in the SLC array. Table 3.2.2gives a description of each plot in terms of the various input signal to noise ratios, and gives an estimate of the improvement.
Figure 3.17	Plots (a) to (d) show the improvement in the effective output to noise ratio for different noise levels in the main-beam array. Table 3.2.2gives a description of each plot in terms of the various input signal to noise ratios, and gives an estimate of the improvement.
Figure 3.18	Plots (a) to (d) show the improvement in the effective output to noise ratio for different noise levels in the SLC array. Table 3.2.3gives a description of each plot in terms of the various input signal to noise ratios, and gives an estimate of the improvement. Each of the above results was obtained assuming multipath interference.
Figure 3.19	Plots (a) to (d) show the improvement in the effective output to noise ratio for different noise levels in the SLC array. Table 3.2.3gives a description of each plot in terms of the various input signal to noise ratios, and gives an estimate of the improvement. Each plot was done assuming multipath interference was present.

Figure 3.20 Sequential 1024 point FFTs of contiguous (1024 point) data segments, for on-target, main-beam data from Run7 March 4 1993

Figure 3.21 Sequential 1024 point FFTs of contiguous (1024 point) data segments, for off-target, main-beam data from Run7 March 4 1993

Figure 3.22 Sequential 1024 point FFTs of contiguous (1024 point) data segments, for on-target, SLC array data from Run7 March 4 1993

Figure 3.23 Sequential 1024 point FFTs of contiguous (1024 point) data segments, for off-target, SLC array data from Run7 March 4 1993

Figure 3.24 (nonexistant)

Figure 3.25 Plots of total received power for high frequency on-target main-beam (raw) and SLC arrays with corresponding off-target cases for Run 4, March 4 1993

Figure 3.26 Plots of received signal amplitude from element 4 of the main-beam and SLC arrays, on and off-target cases, for Run 4, March 4 1993

Figure 3.27 Plots of the phase of the received signal from element 4 of the main-beam and SLC arrays, on and off-target cases, for Run 4, March 4 1993

Figure 3.28 Plots of total received power for high frequency signals from the main-beam and SLC arrays, on and off-target, for Run 11, March 8

Figure 3.29 Plots of received signal amplitude from element 4 of the main-beam and SLC arrays, on and off-target cases, for Run 11, March 8 1993

Figure 3.30 Plots of the phase of the received signal from element 4 of the main-beam and SLC arrays, on and off-target cases for Run 11, March 8

Figure 3.31 Effects of sidelobe cancellation on data from Run 4, March 4. The green indicates the total received power before sidelobe cancellation and the red shows the results after sidelobe cancellation.

Figure 3.32 Effects of sidelobe cancellation on data from Run 11, March 8. The green indicates total received power before sidelobe cancellation and the red shows the results after sidelobe cancellation.

Figure 3.33 Results of Run 4 and Run 11 after averaging over each range cell (1024 data points) and plotting versus range.

Figure 5.1 Test pattern plot to verify the correct operation of the ROTMN1 and READROTMAN software programs

Figure 5.2 Rotman lens amplitude patterns for the eight output channels during Run 1 on Aug. 30 1993

Figure 5.3 Rotman lens amplitude patterns for the eight output channels during Run 2 on Aug. 30 1993

Figure 5.4 Rotman lens amplitude patterns for the eight output channels during Run 3 on Aug. 30 1993

Figure 5.5 Rotman lens amplitude patterns for the eight output channels during Run 3 on Sept. 1 1993

Figure 5.6 Rotman lens amplitude patterns for the eight output channels during Run 4 on Sept.1 1993

Figure 5.7 Rotman lens amplitude patterns for the eight output channels during Run 2 on Sept. 1 1993

Figure 5.8 Rotman lens amplitude patterns for the eight output channels during Run 1 on Sept. 1 1993

Figure 5.9 Rotman lens amplitude patterns for the eight output channels during Run 1 on Sept. 2 1993

Figure 5.10 Rotman lens amplitude patterns for the eight output channels during Run 2 on Sept. 2 1993

Figure 5.12 Rotman lens amplitude patterns for the eight output channels during Run 1 on Sept. 2 1993

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This report summarizes the work done by Advanced Information Technologies Corporation (AIT) in fulfilment of DND contract W7714-2-9607 from October 1992 to November 1993 entitled "Multi Function Radar Counter Counter Measure Studies". The majority of the contract work involved: 1) processing and analysis of data from experimental radar trials at the DREO Area 5 testing site along the Ottawa river, during March, September and August 1993, 2) computer simulation studies of sidelobe cancellation under various noise and propagation conditions, and 3) coding and testing a complex software package for simulating a possible two dimensional phased array configuation for a multi-function radar system.

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Area 5
Array
canceller
EARS
ECCM
jammer
Lake Huron
low angle tracking
Main-beam jammer
MFR
Monopulse
Multifrequency
Multi-function radar
propagation
radar
RML
Rotman lens
Sidelobe jammer
SLC